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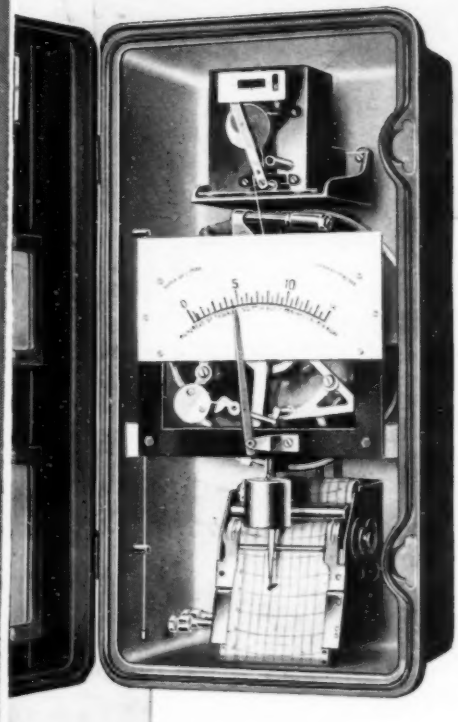
THE BRITISH JOURNAL OF METALS



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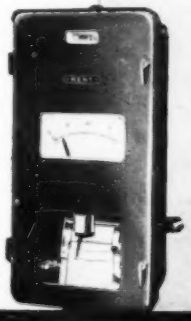

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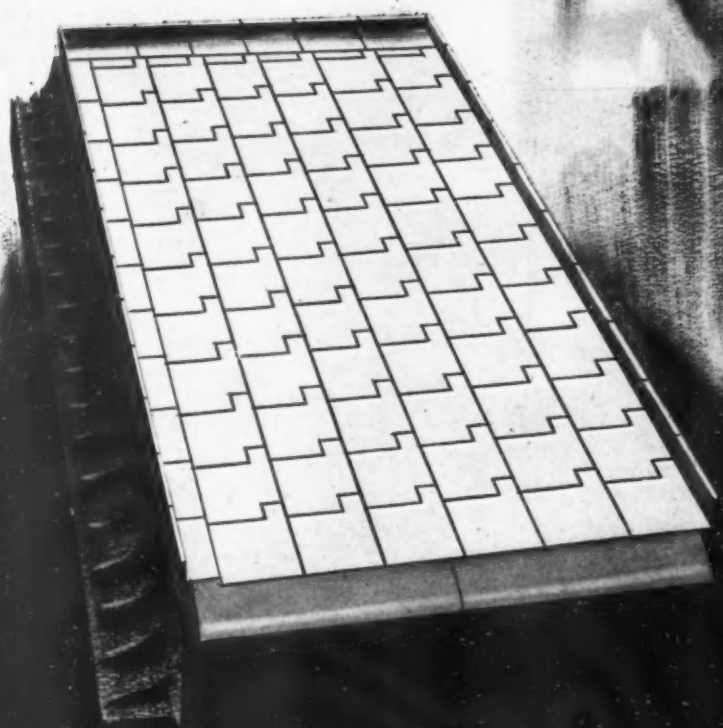

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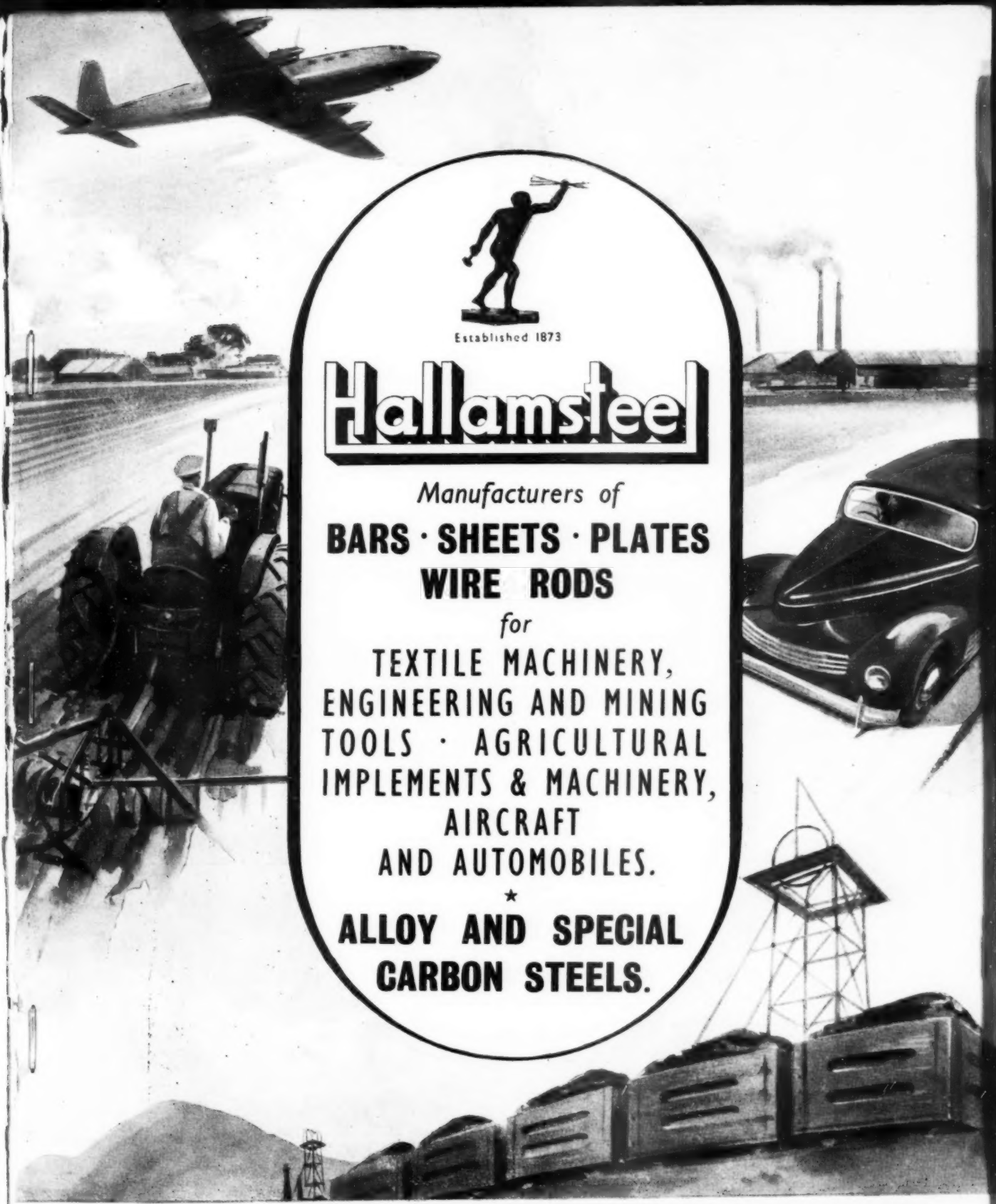

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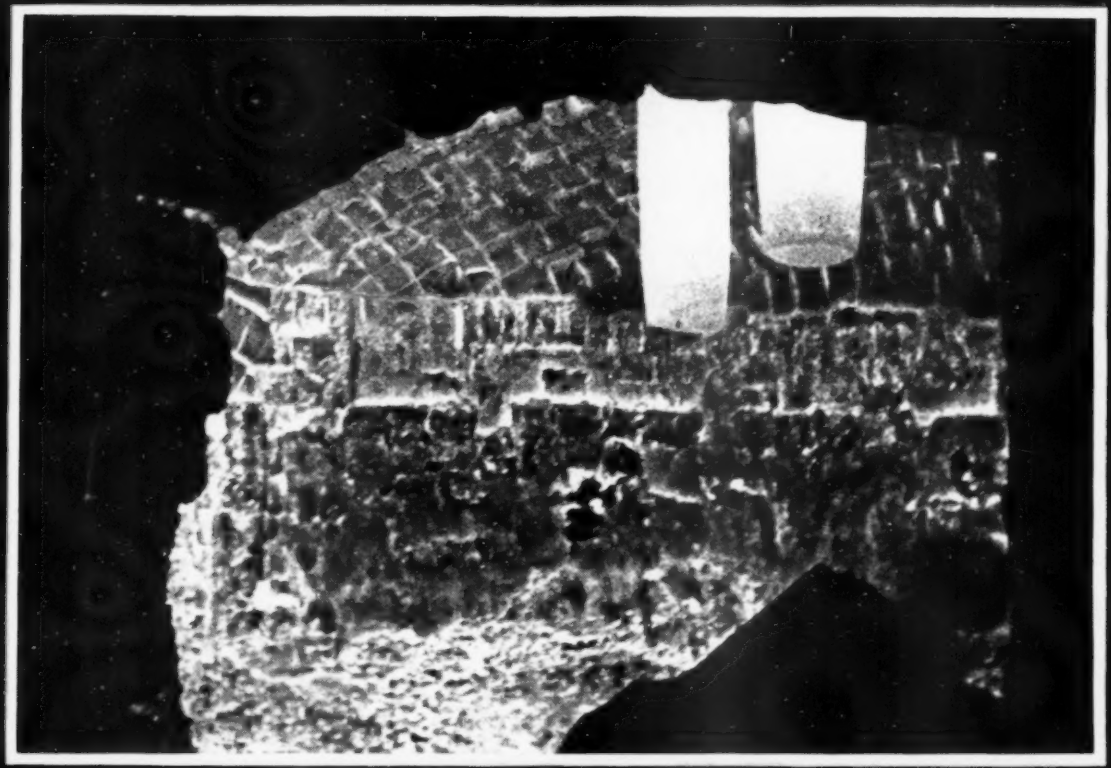
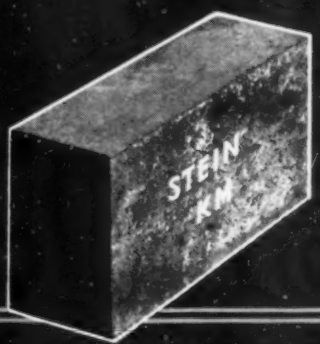


"Stein KM" (burned Chrome-Magnesite) bricks are giving consistently good service in side walls of basic electric furnaces. Photograph shows interior of a 10 ton furnace after 11 weeks' operation. Lining was 9" thick and bricks were jointed using steel sheets. May we send you further particulars?



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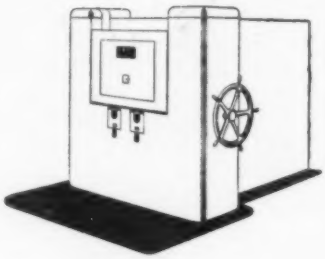

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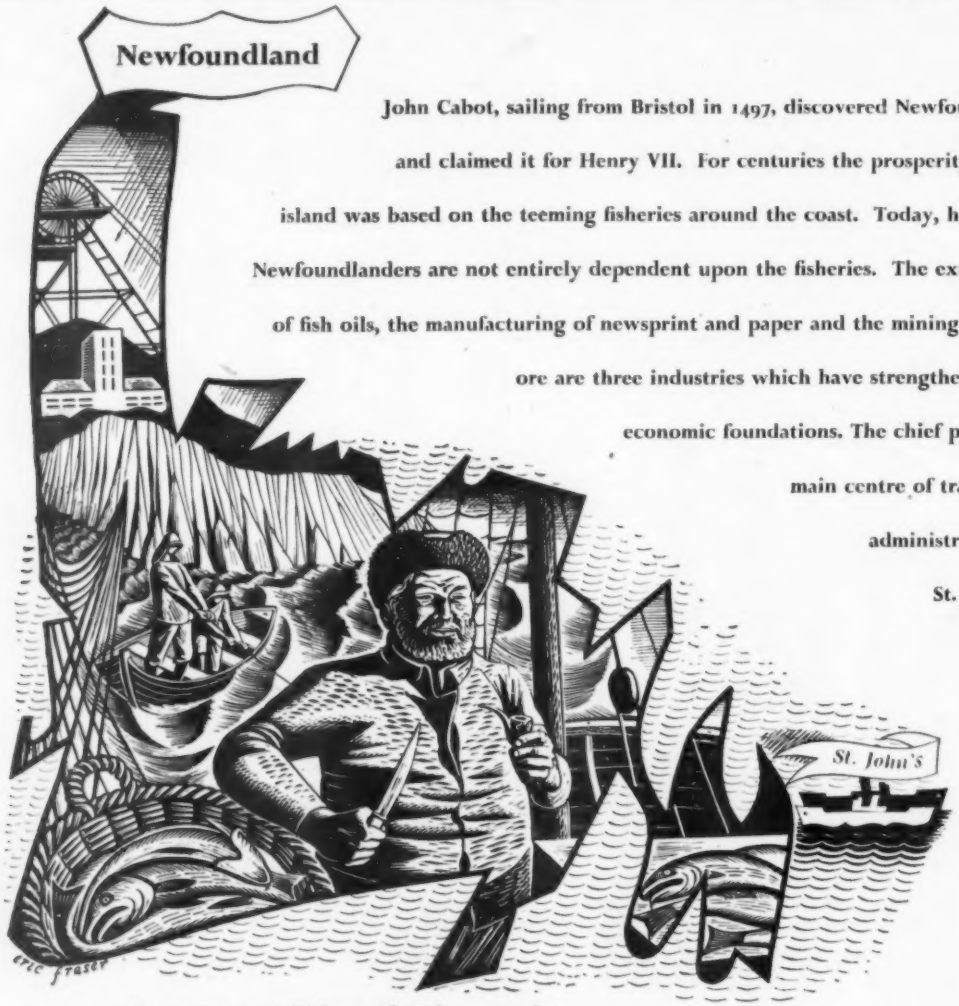

John Cabot, sailing from Bristol in 1497, discovered Newfoundland and claimed it for Henry VII. For centuries the prosperity of the island was based on the teeming fisheries around the coast. Today, however, Newfoundlanders are not entirely dependent upon the fisheries. The extraction of fish oils, the manufacturing of newsprint and paper and the mining of iron ore are three industries which have strengthened the economic foundations. The chief port and main centre of trade and administration is St. John's.

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Fluorspar is one of the essential minerals used in the production of aluminium, a key metal in British Commonwealth trade and industry. With the continued growth in demand for aluminium, Newfoundland gives additional evidence of her place as an important partner in Commonwealth enterprise.

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Principal British Commonwealth Distributor of Aluminium

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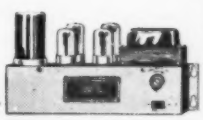

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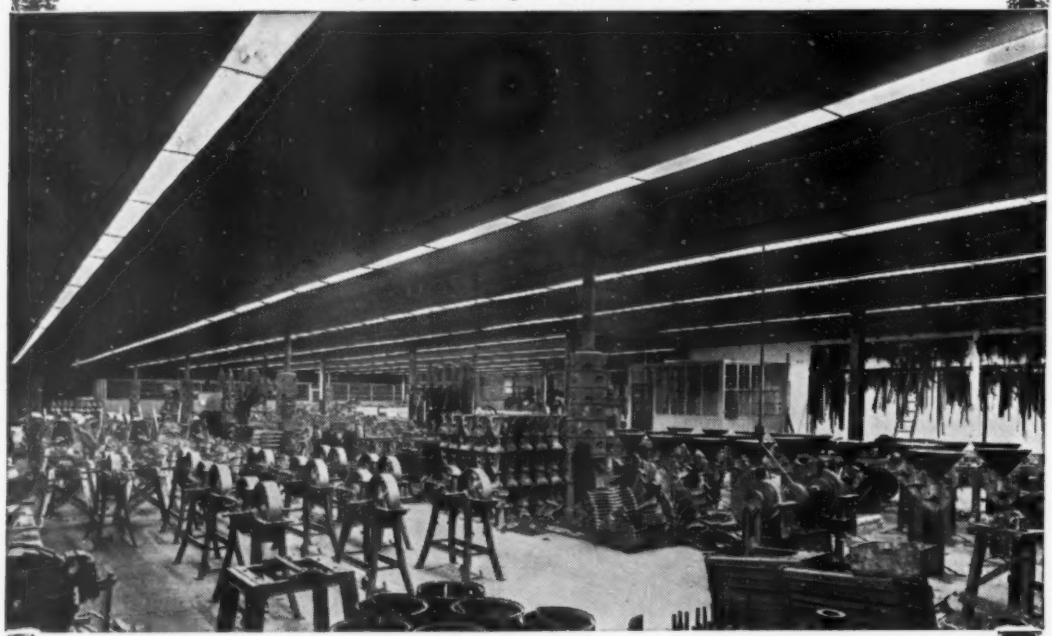

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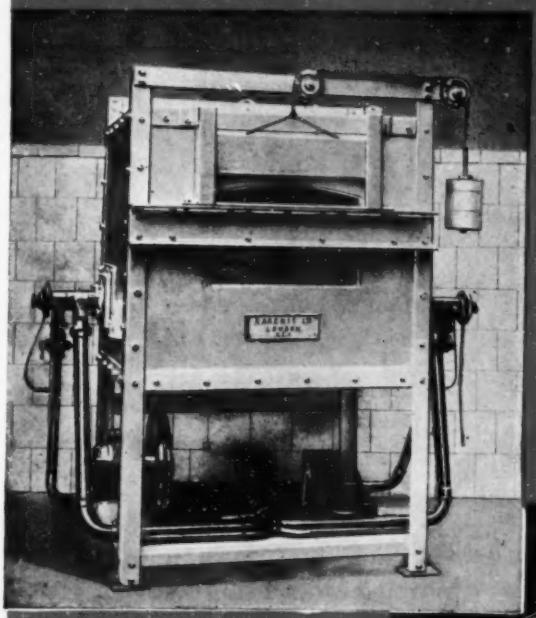

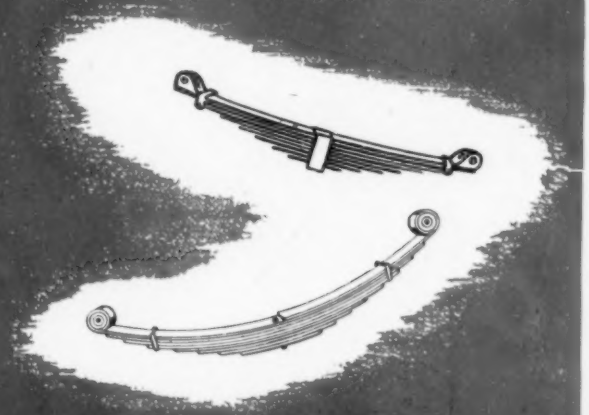

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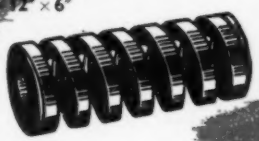

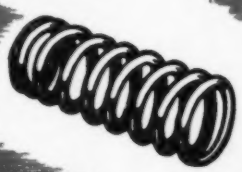

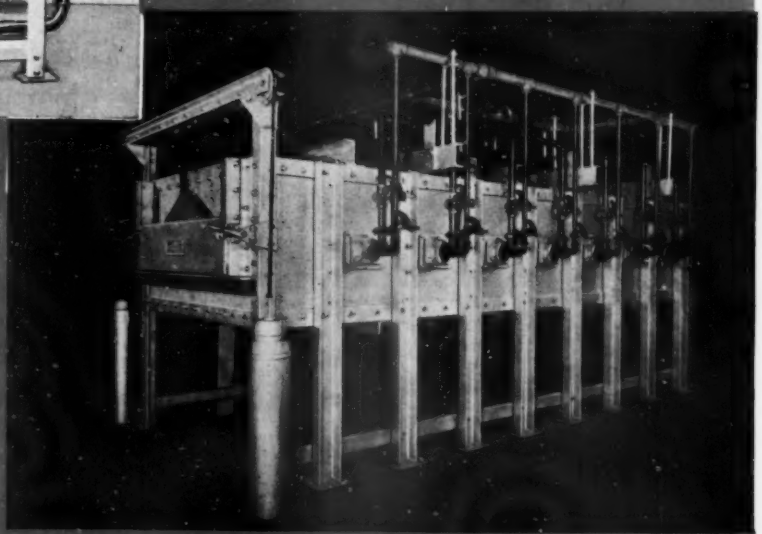

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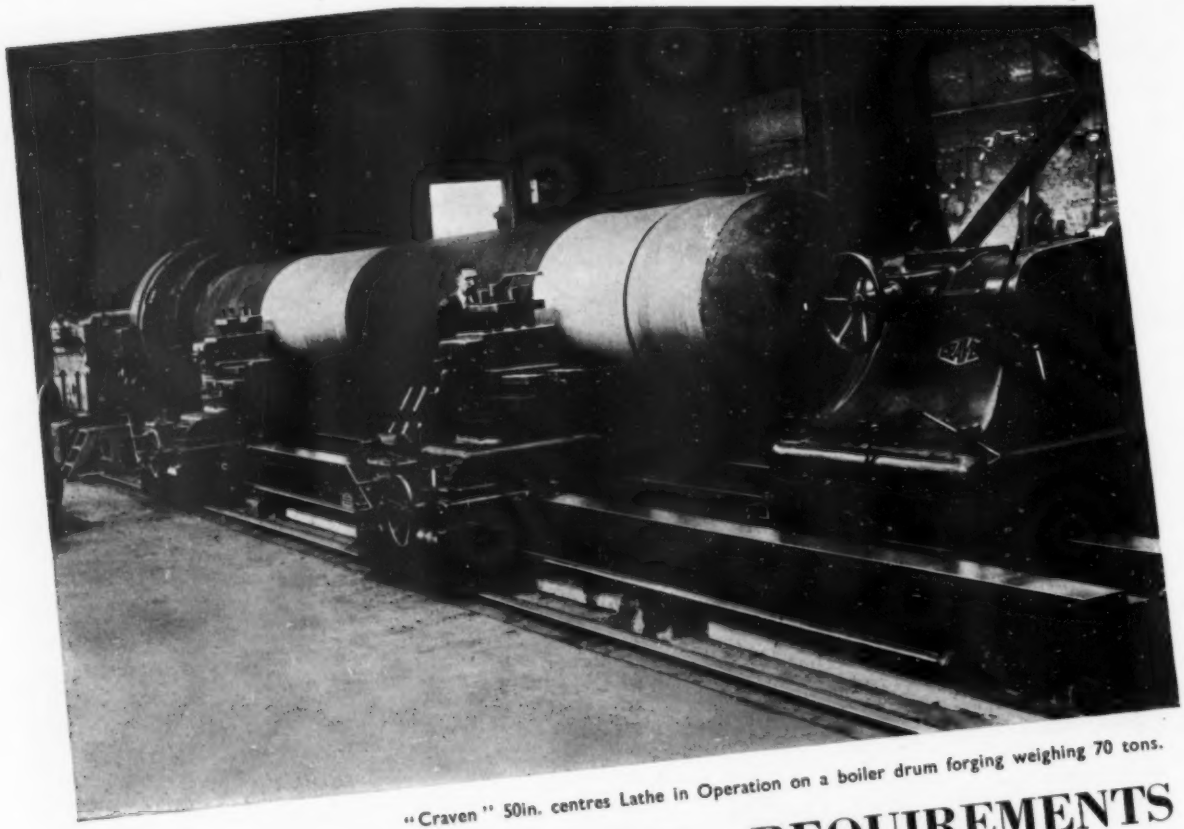

"Craven" 50in. centres Lathe in Operation on a boiler drum forging weighing 70 tons.

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of the calibre shown in the illustration above present no problem to Messrs. Craven Brothers (Manchester) Limited, who are large-scale manufacturers of all types and sizes of lathes from 16" to 100" height of centres. If you are in the market for a large lathe you cannot do better than consult the "Craven" organisation who will submit a suitable machine from their very extensive standard range, or will be pleased to develop a design around your own specific requirements.

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Fig. 1 shows the "CAPACITROL" Automatic Temperature Controller capable of controlling electric, gas and oil-fired furnaces and apparatus utilising the On-Off or By-Pass system of control.

Fig. 1.

Ether-Wheelco "Capacitrol" Automatic Temperature Controller.

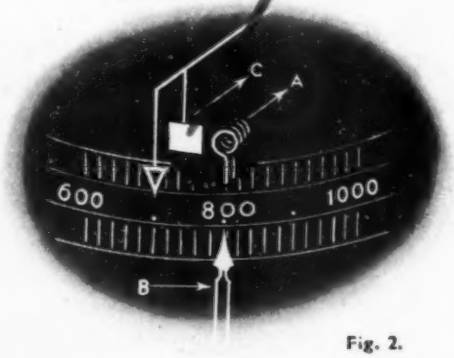

Fig. 2.

Fig. 2 shows the way in which the science of electronics is used to automatically control temperatures, with the speed of light, great accuracy and no interference with the measuring system. A light aluminium flag "C" passes between two coils "A" of the electronic system, when the flag enters the sphere of influence of the coils a movement of a few thousandths of an inch is sufficient to switch the control system off and on. By moving the coils attached to the pointer "B" the control position can be readily adjusted.

Other types are made giving two position and proportional control, these are known as the "MULTRONIC" and "PROPORTIONAL CAPACITROL."

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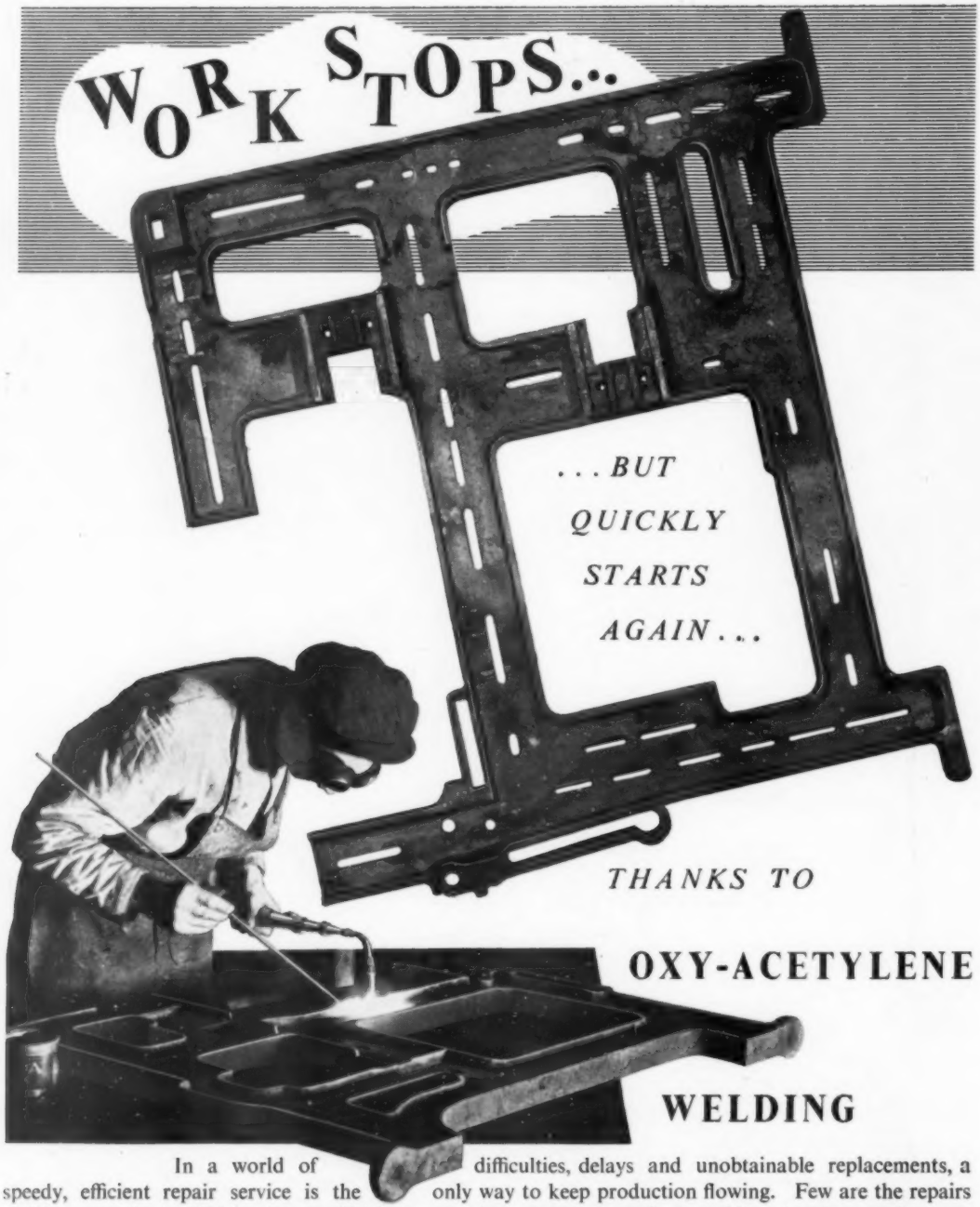

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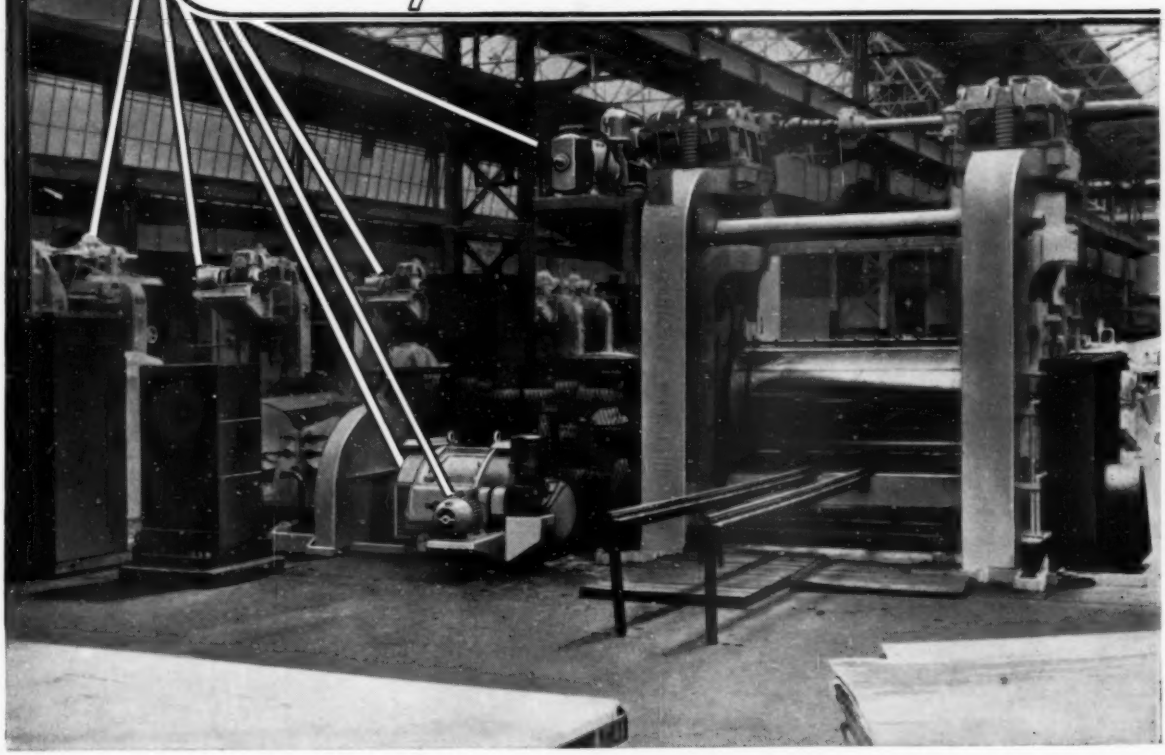
THE BRITISH OXYGEN CO LTD LONDON AND BRANCHES

The drive behind the output of the mill



The photograph shows Metrovick motors driving a Brightside cold sheet mill for finishing aluminium sheets.

Main drive : 150 hp 585 r.p.m. continuously rated slipring motor.

Screw down : 12 hp Type DK motor fitted with 10" Perigrip brake.

Grease pump : 1½ hp totally enclosed fan cooled S.C. motor driving pump for continual supply of grease to roll necks.

In the background the screw down gear seen on the 4 stand sheet mills is also driven by 12 hp Metrovick motors.

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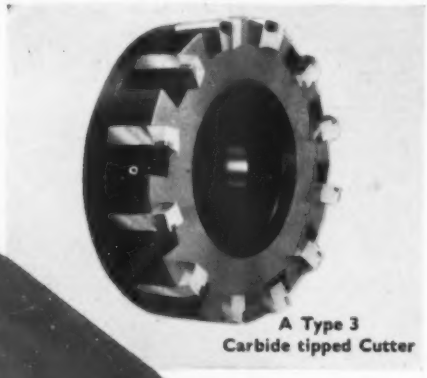

A Type 3
Carbide tipped Cutter

A Carbide tipped Circular Saw

A Carbide
tipped Reamer

"MITIA"
CARBIDE TIPPED TOOLS

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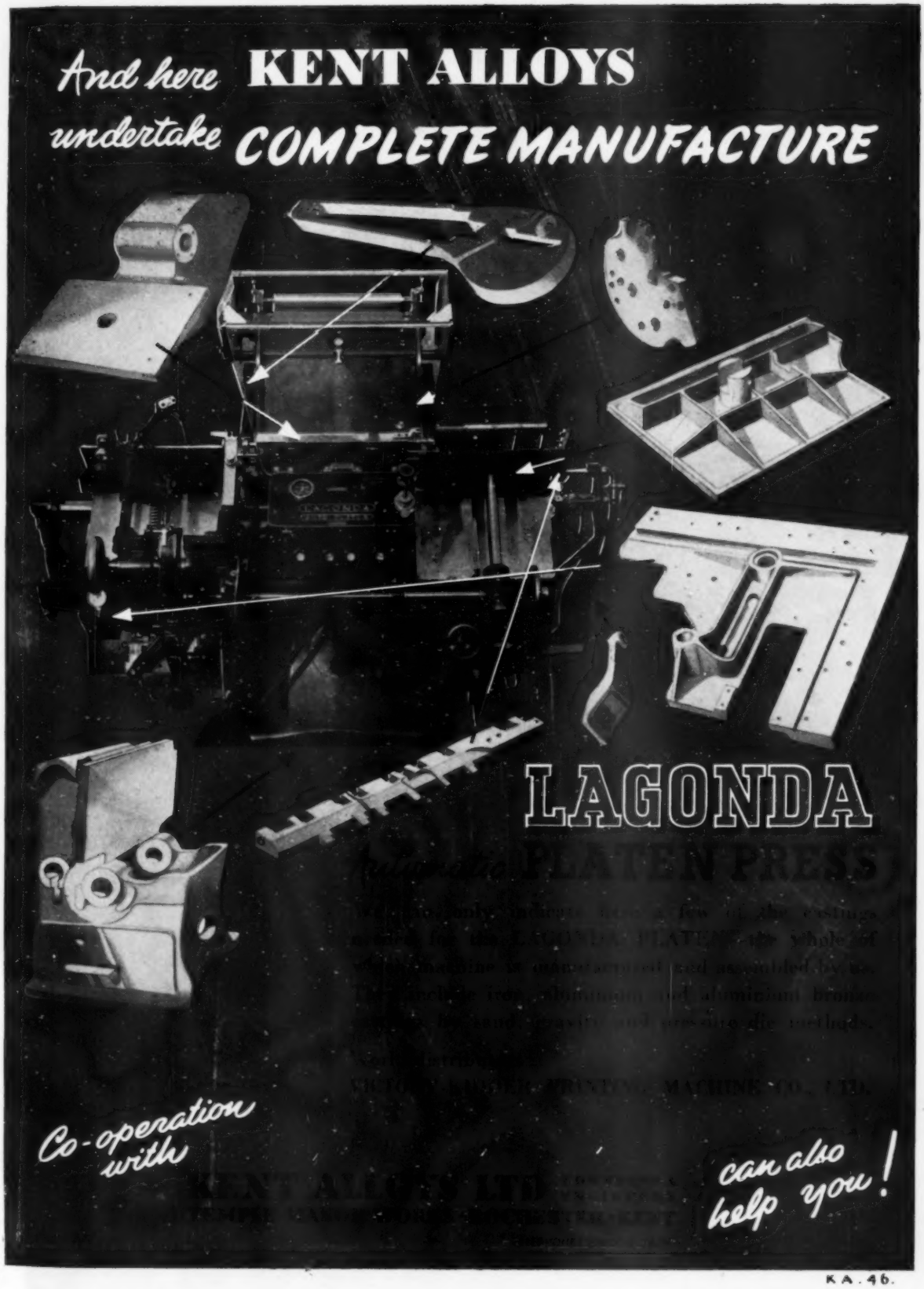
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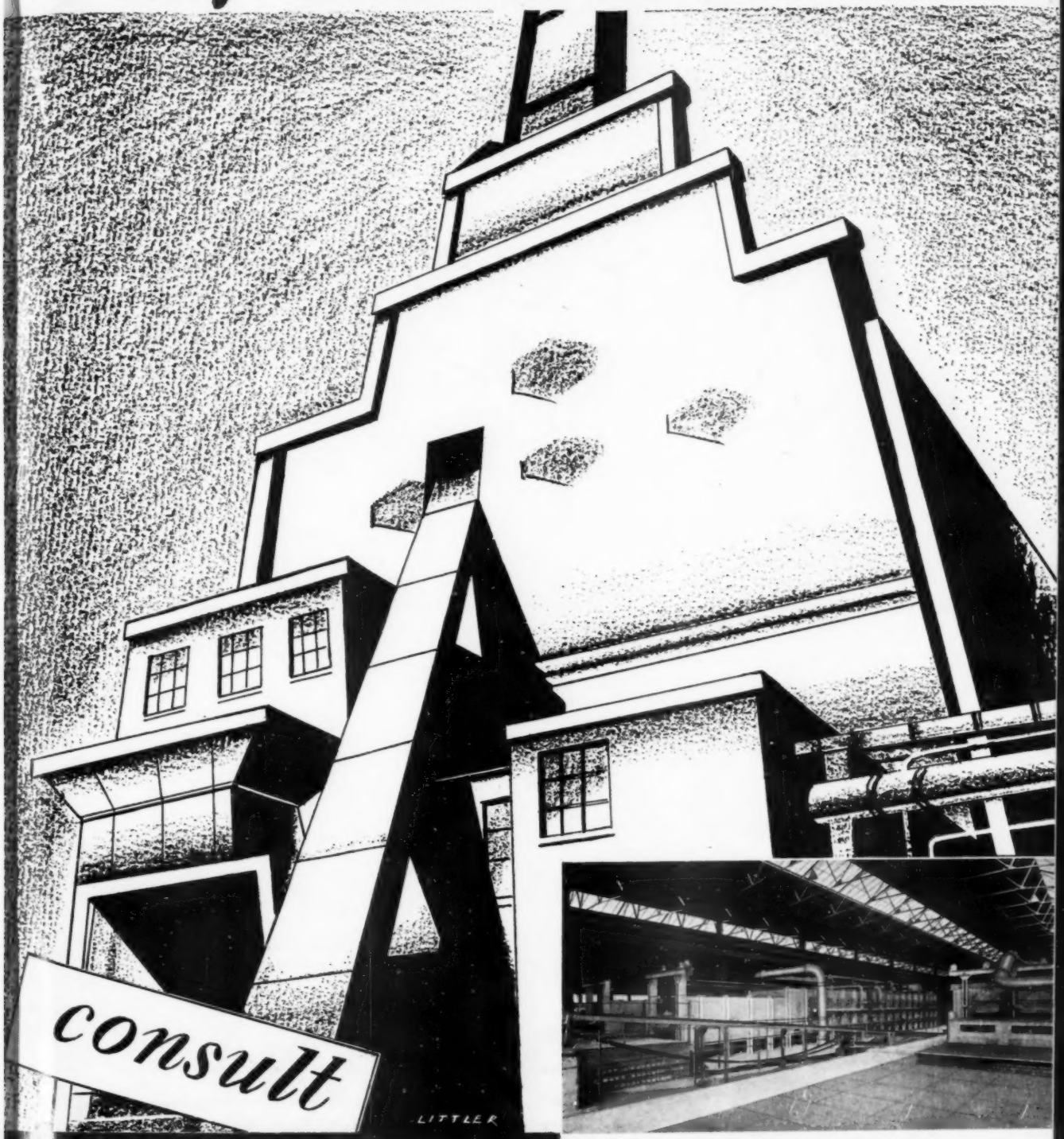

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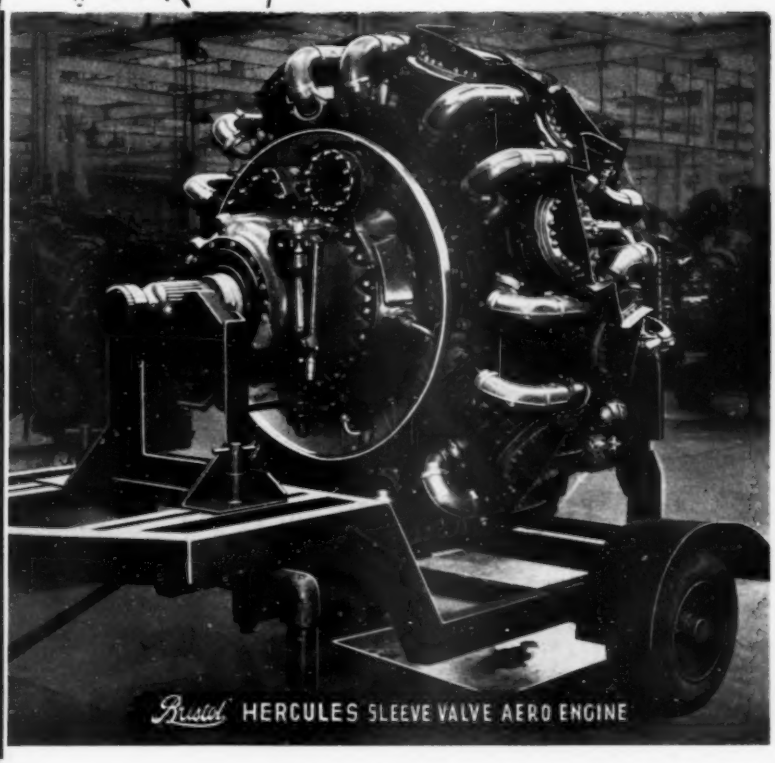

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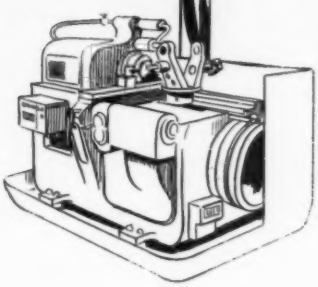

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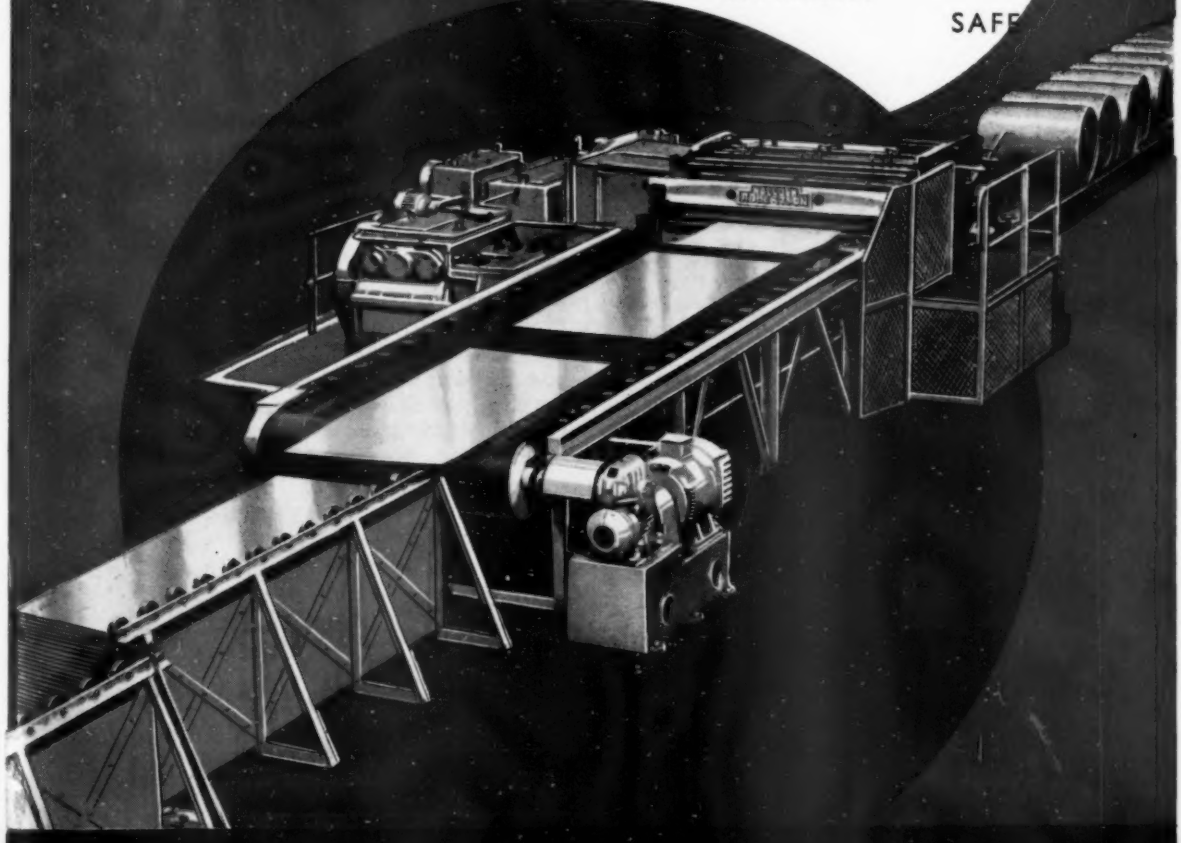

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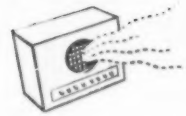

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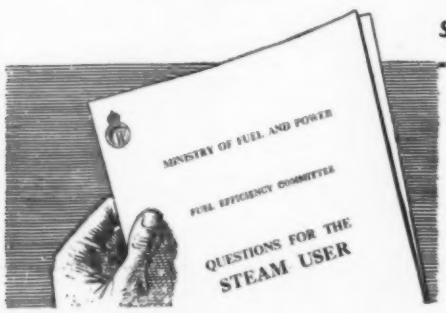

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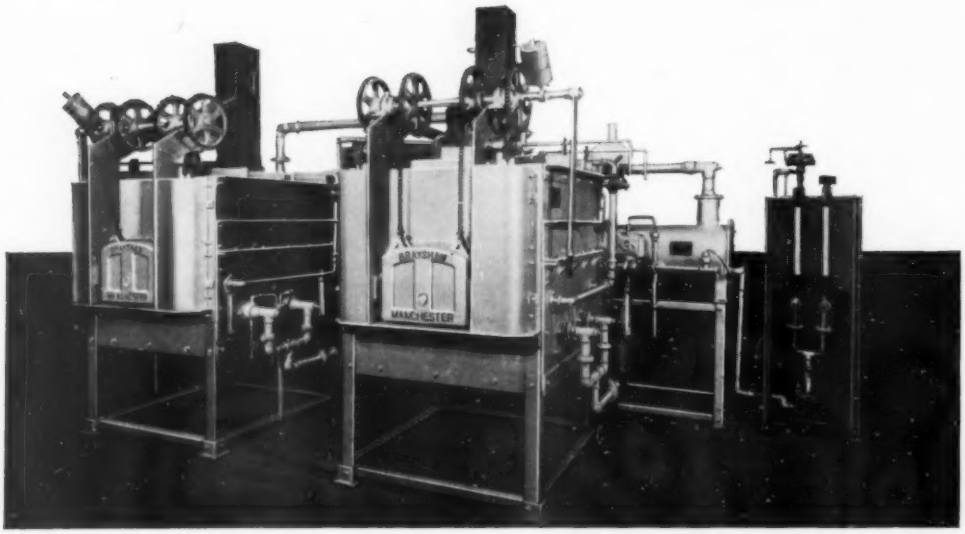

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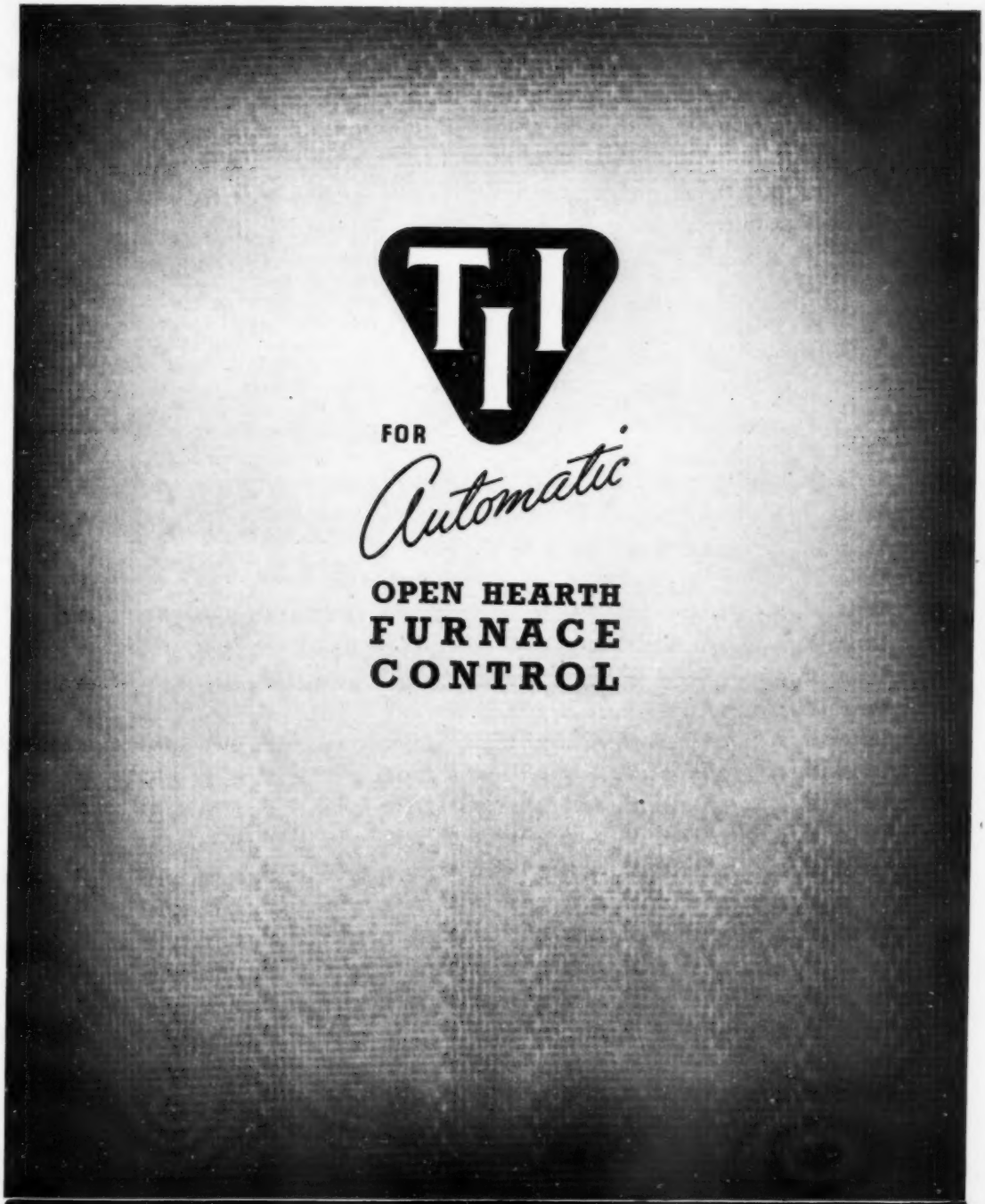

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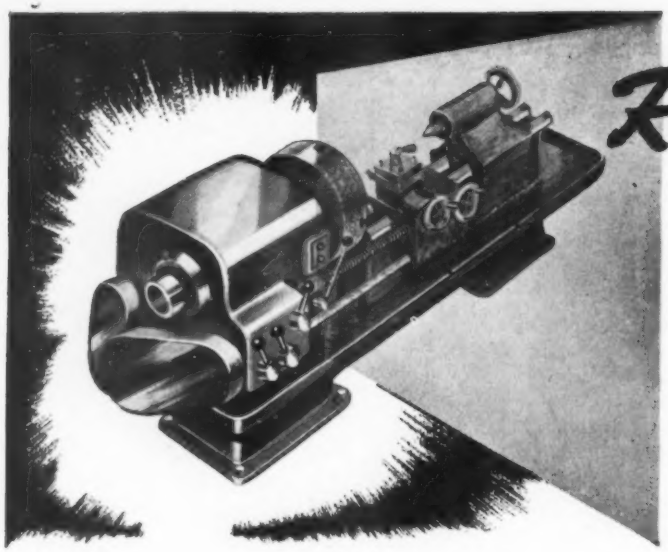

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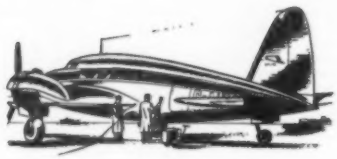

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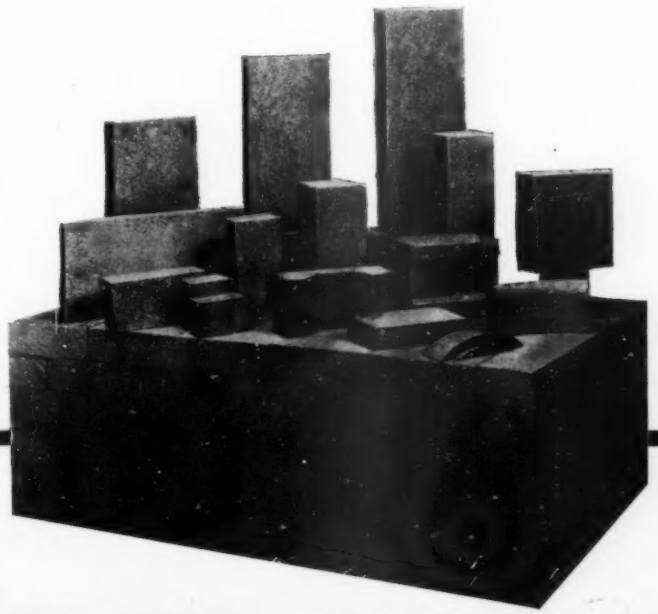

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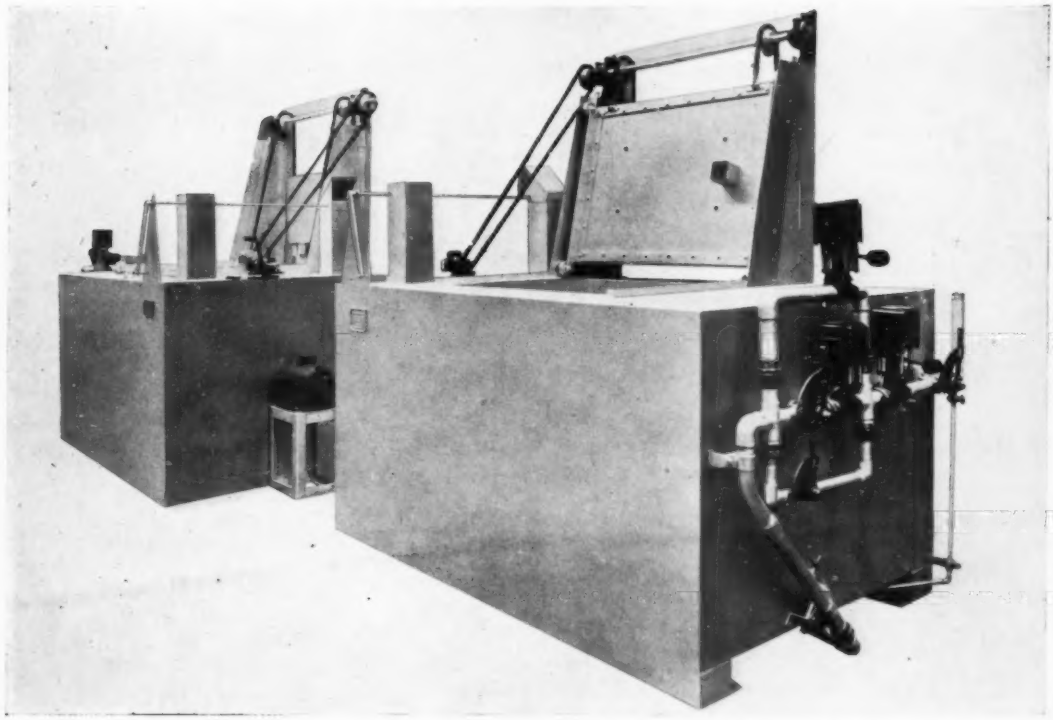

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SEPTEMBER, 1949 Vol. XL No. 239

Industrial Research

QUITE recently two well-known public figures had something to say on the nation's production. Mr. Brendan Bracken referred to workers who oppose, by various means, the introduction of new machinery and new processes that increase output, as the new Luddites. A few days afterwards, Sir William Lawther told the Trades' Union Congress that unofficial strikes are wild-cat disturbances and demanded that they should be outlawed by the workers. Although perhaps looking at Britain's economic position through different coloured glasses, both were actuated by the same motive —the need to increase production and the need for a combined national effort to lift the country clear of its present economic difficulties. It would seem, therefore that man, rather than matter, is the chief obstacle to progress, for science is being so applied to matter as to greatly widen man's horizons and increase his knowledge. Applying this knowledge is undoubtedly contributing in no small measure to a solution of the world's problems. It is being applied successfully in overcoming disease and in reducing physical pain ; here, however, we are concerned with one of its many phases in which persistent research is necessary to improve and cheapen production and to develop new products. We must look ahead if we are to prosper and a real national effort is overdue.

A little thought will show that research has either been the beginning of, or has a leading part in, the development of every modern industry. New processes, new machines, new materials, and new applications of these materials have been developed through research. Indeed, under modern conditions, an industry can thrive and develop only through such discoveries and their applications, and that the future welfare of practically every industrial firm is closely connected with further developments of their products through research.

Many have the impression that a discovery or a development is the result of a sudden inspiration or imagination on the part of an investigator, but discoveries of this nature are rare. By far the greater amount of progress is effected by patient step-by-step search for solutions to problems and, almost invariably, many investigators contribute time, thought, and effort toward the final result. It is true that in pure research the scientist follows up an idea in the search for new truths of nature and of the elements that occur on the earth, but he is less interested in the application of these truths. His main desire is to open new territories of knowledge. The discovery by Lord Rutherford and his associates of the possibility of splitting the atom is a typical example of such pure science.

Industrial research, as Christie* states, is concerned with the exploration and development of the new territories opened up by the pure scientist. The researches are generally undertaken with definite objectives in view. While there is the same urge to learn truth regarding the subjects treated, in general the object of industrial research is to find something in the new territory of science, or even to work over old territory, which is likely to be of use and benefit to mankind or will prove profitable to industry. The work may result in the discovery of a new alloy or the improvement of a familiar one ; the production of a new or improved process or machine, which increase or improve production, or provide for increased service from products. It is simple economics to make the best possible use of the raw materials available and research is a big contributing factor. Reference must be made also to work on laboratory and industrial instruments to facilitate production or for the inspection of products, or to provide improved facilities for the investigation of materials.

One of two methods may be employed in carrying out industrial research, although they are frequently combined. Assuming that the investigator is working on a particular problem, one method is to try everything that might relate in any way to the object of the research, noting results. Keen observation and analysis, endless patience, and ability to use common sense and reasoning in making correct deductions from results, are essential. The proper solution may be found but at the expense of much time and money. The more modern method proceeds along scientific lines. When a certain need or objective is formulated, a theory is developed by thoughtful analysis and study of facts already known. This will involve a survey of literature to collect all relevant facts. The investigator then proceeds to test his theory in the laboratory and, by analysis of data and modification of theory as a result of tests, further tests will be carried out which finally lead to a solution of the problem.

With few exceptions, there is a considerable time lag in the application of a development arising as a result of research. Many factors are responsible for this delay, notably financial stringency and lack of plant and staff, but often because capital has been invested and production is in operation on a product which would be almost entirely displaced by a new product developed as a result of research. Gradually, however, it is being appreciated that, to maintain a progressive position, British industry must make a steady and persistent study of the many problems that continually arise. Advances in engineering science and practice are bound up with the development of available materials of which ferrous and non-ferrous metals play a dominant part. But, discoveries in the metallurgical field are few, and when they do occur they are generally the prelude to much research before they can be profitably applied. Reports on recent work of some of the co-operative associations are presented elsewhere in this issue.

* *Mech. Eng.* 1949, **71**, 580.

B.S.1133 Packaging Code

SO much of the success of the production and export drives depends upon efficient packaging that the new British Standard Packaging Code, published the first of this month, is of national importance and should be carefully studied by all exporting firms, particularly those who contemplate competing in overseas markets.

The present issue is a second-edition. The initial issue which it supplants was prepared as a result of a request by the war-time Ministry of Production in 1943 to prepare a comprehensive Code of Packaging. At that time losses of material and equipment were running high through faulty packaging and hazardous wartime shipment to the Middle and Far East theatres of war. The first code, therefore, was mainly to guide Service and Government Departments, and their packaging contractors, in selecting and determining the right type of packaging for any product, the materials to use, and the method of construction. To-day, the export drive has supplanted the Forces as the ' target ' for the Code, but one consideration remains supreme—the avoidance of preventable losses of any kind. As in war, Britain's production machine has enough to do without being called upon to replace goods lost through deterioration or damage on transit. The loss of a battle may not be traced back to the packer, but the loss of an export market most emphatically can be.

Considerable structural and textical changes have been made to the Code to suit present-day needs. Several sections of the first edition have been sub-divided and merged with others. Other sections have been merged, expanded, and new sections added. The work is too large to issue, or even to compile, as one complete entity. It is therefore being published as 17 sections, as and when ready. The first three sections are grouped together as the " Introduction to Packaging " in which the principles governing design, construction and materials are outlined. This is the all-important basic approach to the Code and is now being issued, price 4s., net, post free. The individual sections included in it are : (1) Choice of containers and method of packaging ; (2) storage of containers and packaging materials ; and (3) addressing, marking and identification.

Five other sections are also available in completed or provisional form, viz. : (8) Wooden containers (6s. net, post free) ; (9) Textile bags, sack and wrappings (3s. net, post free) ; (11) Packaging felt (2s. net, post free) ; (14) Adhesive closing and sealing tapes (2s. 6d. net, post free) ; and (15) Tensional steel strapping (2s. net, post free).

Four sections are in an advanced state of preparation and will be issued in the near future. The concern (4) Mechanical handling of packaging materials and filled containers ; (6) Protection against corrosion ; (7) Paper wrappers and containers, including films, foils and laminates ; and (17) wicker and veneer baskets. Work is proceeding as rapidly as possible with the remaining sections which deal with (5) Protection against pest and mycological attack ; (10) Metal containers ; (12) Cushioning materials other than felt ; (13) Cordage ; and (16) Adhesives for packaging.

Each section, as a rule, gives definitions of the materials or method concerned, notes on their use, standards of performance required, methods of testing, and illustrations of uses and testing appliances. A glossary of packaging terms is also in preparation. Copies of the Introductory and other Sections, as published, may be obtained from the British Standards Institution, Sales Department, 24–28, Victoria Street, London, S.W.1.

British Aircraft

THOSE fortunate enough to see the display fo British aircraft at the recent show, staged at Farnborough and organised by the Society of British Aircraft Constructors, could not fail to be thrilled. It was undoubtedly the most interesting display of any held in this country and attracted big crowds who apparently appreciated that British developments are not exceeded by any country. Not so long ago it seemed that British air lines would be forced to rely on United States machines for some years, but the position has radically changed in the last year and to-day there seems every likelihood that United States air lines will consider it profitable to use a number of British machines.

Some 61 aeroplanes were on view, between 40 and 50 of which were included in the actual flying programme. Of particular interest was the large number of British turbine and propeller turbine-powered military and civil aircraft. Of the former, probably the most outstanding were the Vickers 510, the Hawker P1052 and the English Electric Canberra, the first two being single-seater fighting prototypes and the third a fast bomber driven by two turbines. Of the civilian aircraft the De Havilland Comet probably provided the biggest surprise. This 36-seater airliner had its first flight at the end of July and finished its preliminary trials without incident in a remarkably short time. At Farnborough this jet airliner was flown at high speed and its beauty of movement and control must have been the envy of many airline officials, whether British or foreign. Airline operators must have been not less interested in the Handley-Page Hermes, the Vickers Viscount and the Armstrong-Whitworth Apollo with their turbine-driven propellers.

The speed of the fighter aircraft was a revelation to many spectators and while it is impossible to judge with aeroplanes in the 600 m.p.h. class, it did seem that the Vickers 510 was the fastest on view at Farnborough, although the Hawker P1052 was also in this class and was certainly comparable. The remarkable rates of climb of standard types of fighter in current use in the R.A.F. were amazing and were favourably commented upon.

There were many piston-engined types of aircraft on view, but the appearance of the Brabazon I on the second day probably stole the show for this type. Flying at a comparatively low altitude across the aerodrome it looked immense, as it undoubtedly is in comparison with other aircraft on view. This eight-engined airliner is not intended for commercial use, but as a means of investigating the possibilities of large airliners ; it is, therefore, regarded as a research plane. The second Brabazon, now under construction at Filton, will be powered by turbine-driven propellers and will incorporate developments resulting from investigations with the present prototype.

Farnborough provided a very satisfying spectacle and indicated that British manufacturers, particularly those developing jet engines, are in the forefront of aircraft design and construction, and the Society is to be congratulated on a very fine effort.

The Welding of Aluminium Alloys

Investigation of Associated Problems

By W. I. Pumphrey, M.Sc., Ph.D.

(From the School of Industrial Metallurgy, University of Birmingham)

The work described in this paper has been carried out in the Department of Industrial Metallurgy of the University of Birmingham as part of a long-term investigation, sponsored by the Aluminium Development Association, into problems associated with the welding of aluminium and its alloys. The work of the welding research team was started in an endeavour to discover the reason why some aluminium alloys are not readily weldable, and, as a result of the information so obtained, to suggest such modifications to chemical composition, mode of manufacture or welding procedure as may be necessary to enable the production of good, high-strength welds in these alloys.

CERTAIN commercial aluminium alloys crack at high temperatures (that is, at temperatures above the solidus) during the welding operation or at much lower temperatures during the cooling of the weld complex. While it is of importance to recognise the occurrence of the latter type of cracking, the former type is the cause of more industrial failures, and the initial work of the team, on the subject of weld cracking, was directed to an investigation of the nature of high temperature cracking, and to the development of methods for measuring the susceptibility of aluminium alloys to cracking of this nature. Cracking at temperatures above the solidus also occurs in castings of certain aluminium alloys, and it was recognised during the early stages of the investigation that, since the operations of casting and welding both involve the solidification of liquid metal under varying degrees of restraint, a knowledge of the factors affecting cracking during casting can assist in the development of methods for minimising cracking during welding. Subsequent investigations were therefore designed to obtain information regarding the factors which affect cracking during either operation, in order to permit the ultimate formulation of a general theory of the occurrence of cracking, at temperatures above the solidus, in castings and welds in aluminium alloys, and, on the basis of this theory, to suggest suitable methods for preventing, or minimising, the occurrence of such cracking in practical conditions of welding. Examination was also made of the factors affecting cracking at temperatures below the solidus, again with the object of suggesting methods for avoiding such cracking during welding.

Throughout the investigation all welding was effected by means of the oxy-acetylene torch because it is considered that since welding merely involves, in essentials, the solidification of liquid metal under some degree of restraint, and the subsequent cooling of the solid weld complex, the principles underlying the behaviour of metal in such conditions will be the same whether the welding is effected by the oxy-acetylene torch or by electrical means. In addition, the course of the investigation was directed to obtaining some information on the mechanical properties of alloys with good welding characteristics in order to enable recommendations to be made as to suitable aluminium alloys from both the strength and the welding aspects.

Cracking at Temperatures above the Solidus

Many investigations have been carried out with the object of determining the nature and the cause of the cracking that occurs during the casting and welding of certain aluminium alloys, in order to develop methods for preventing the occurrence of such cracking in industrial conditions. In particular, mention should be made of the work of Archbutt, Grogan and Jenkin[1], Scheuer,[2] Verö,[3] Bochvar and Makimdzhanova[4] and Lees[5]. The early work on this subject was, however, largely uncorrelated, being, in the main, directed to the development of methods for the avoidance of cracking in particular alloys of industrial interest, and it was not until the work of Singer and his colleagues that any comprehensive investigation of the problem was begun.

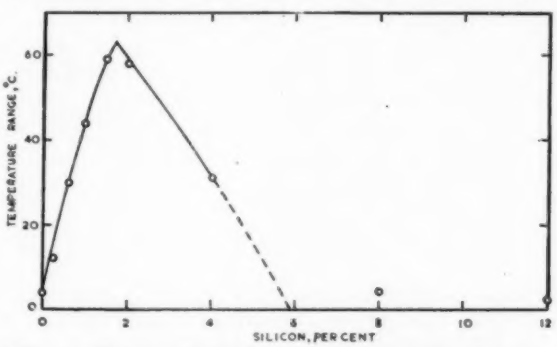


Fig. 1.—Extent of the temperature ranges above the solidus in which strength is retained in aluminium-silicon alloys of commercial purity. (Singer and Cottrell.)

Singer and Cottrell[6] determined the tensile properties of a number of aluminium-silicon alloys of commercial purity at temperatures in the region of the solidus, and found that the strength of each alloy decreased as the temperature of testing was increased. At the solidus temperature the elongation and reduction of area fell to zero with the first appearance of liquid in the mass, and the strength dropped rapidly to a small but measurable value. In certain of the alloys this small strength was retained up to a temperature between the solidus

1 Archbutt, S. L., Grogan, J. D. and Jenkin, J. W., *J. Inst. Metals*, 1928, **40**, 219.
2 Scheuer, E., *Metallwirtschaft*, 1935, **14**, 337, 367.
3 Verö, J., *Met. Ind. (Lond.)*, 1936, **48**, 431, 491.
4 Bochvar, A. A. and Makimdzhanova, M. K., *Metallurg.*, 1939 (2), 75
5 Lees, D. C. G., *J. Inst. Metals*, 1946, **72**, 343.
6 Singer, A. R. E. and Cottrell, S. A., *J. Inst. Metals*, 1946, **73**, 33.

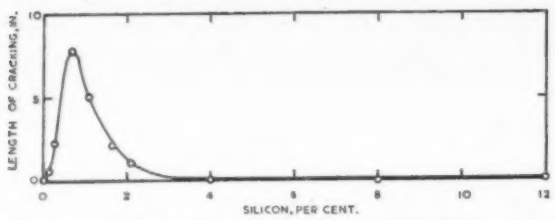


Fig. 2.—Cracking of ring castings in aluminium-silicon alloys of commercial purity. (Singer and Jennings.)

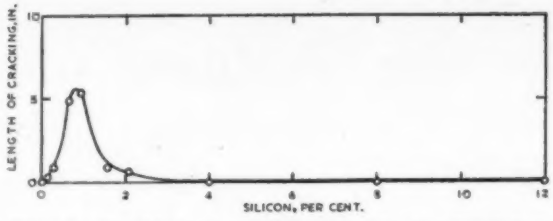


Fig. 3.—Cracking of restrained welds in aluminium-silicon alloys of commercial purity. (Singer and Jennings.)

and liquidus at which so much liquid was present between the crystals of the metal that coherence was lost and the strength fell to zero. The extent of the temperature range above the solidus in which strength was retained was found to be dependent upon the chemical composition of the alloy, and, with aluminium-silicon alloys of commercial purity tested under conditions of structural equilibrium, rose, as shown in Fig. 1, from zero with pure aluminium to a maximum at 1·8% silicon, and then decreased to a small value at higher percentages of silicon. It was suggested by Singer and Cottrell that the extent of the temperature range above the solidus in which alloys have a small, finite strength but no ductility—termed by them the hot-short temperature range—is one of the most important factors in determining the tendency of such alloys to crack, at temperatures above the solidus, during casting and welding.

Testing Procedure

Casting and welding experiments were subsequently carried out by Singer and Jennings[7] to determine the effect of silicon content on the tendency of aluminium-silicon alloys to crack at high temperatures under such conditions. The casting test developed for this purpose consisted of casting the alloys into the annular cast iron mould shown in Fig. 4 (a and b), each alloy being cast from a temperature 100° C. above the appropriate liquidus temperature. During solidification and subsequent cooling, tensile stresses were set up in the metal due to the restraint of free contraction by the solid core of the mould, which caused cracking in brittle or hot-short alloys. Four, eight, twelve or sixteen rings were cast in each alloy, and the average total length of all the cracks on the surface of a cast ring of each alloy, when cold, was taken as a measure of the tendency to cracking in the particular alloy considered. The welding test consisted of welding together, under conditions of restraint, two sheets of the same alloy, each 5 in. × 4 in. × 14 g., and measuring the amount of cracking appearing on both surfaces of the weld after cooling to room temperature in the restraining jig. The jig used in the restrained welding tests is illustrated in Figs. 5(a) and 5(b).

The amount of cracking occurring in ring castings and restrained welds, in alloys of commercial purity in the aluminium-silicon system, is shown plotted against silicon content in Figs. 2 and 3. In both tests the severity of cracking was found to rise rapidly from zero with increasing additions of silicon to commercial purity aluminium to a maximum at approximately 0·7–0·8% silicon, and then to decrease less rapidly to zero at a silicon content of 2–3%. The close agreement between the results of the ring casting and the restrained welding experiments suggested that the same factors were responsible for cracking during both casting and welding of aluminium-silicon alloys, and Singer and Jennings were able to correlate the variation of cracking with increasing silicon content in the two operations with the corresponding variation of the hot-short temperature range. The nature of this correlation may be understood by reference to Fig. 6 (a and b). If the corner of the equilibrium constitutional diagram for a simple binary aluminium alloy system, such as the aluminium-silicon system, which has a single eutectic, is assumed to be as shown in Fig. 6 (a), and AC is the line joining the temperatures at which complete loss of cohesive strength occurs, then, according to Singer and Cottrell, the temperature interval between the lines ABD and AC is a measure of the hot-short temperature range, or the brittle range, for any alloy considered. The temperature interval between the lines ABD and AC is plotted against composition (silicon content for example) in Fig. 6 (b). From Fig. 6 (b) it would seem that the temperature interval, i.e., the hot-short temperature range, should rise to a maximum at a composition corresponding to the limit of solid solubility of alloying element—point E in Fig. 6 (a)—a deduction which is in agreement with the experimental results obtained by Singer and Cottrell in their high-temperature tensile tests on aluminium-silicon alloys. Singer and Jennings suggested that the cracking in the restrained

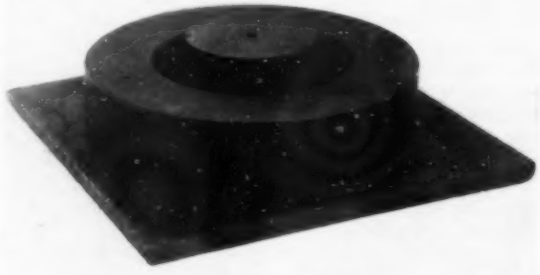


Fig. 4a.—Mould used for ring casting tests.

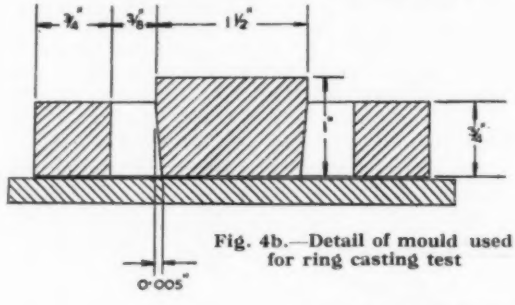


Fig. 4b.—Detail of mould used for ring casting test

7 Singer, A. R. E. and Jennings, P. H., *J. Inst. Metals*, 1946, **73**, 197.

welds and ring castings occurred entirely at temperatures above the solidus. On the basis of this suggestion the maxima in the cracking curves for aluminium-silicon alloys would be expected to occur at 1·8% silicon. The maxima in the curves reproduced in Figs. 2 and 3 occurred between 0·7 and 0·8% silicon, however, and it was postulated that the difference in the positions of the maxima in Figs. 2 and 3 and in Fig. 1 was due to the leftward displacement of the equilibrium solidus due to the non-equilibrium conditions obtaining in the ring casting and restrained welding tests. By means of this hypothesis, Singer and Jennings were able to correlate the tendency for cracking to occur in castings and welds with the extent of the hot-short temperature range and with the probable constitution of the alloys in the conditions obtaining in casting and welding.

The forms of the constitutional diagrams for aluminium-silicon alloys, applicable to such meta-stable conditions as obtain during casting and welding, were later determined by Pumphrey and Jennings[8] by means of tensile tests carried out on alloys rapidly heated from the solid state to temperatures above the solidus, and rapidly cooled from the liquid state to temperatures below the solidus. As a result of this experimental work Pumphrey and Jennings were able[9] to amplify the earlier, limited theory of Singer and Jennings and they suggested that cracking, in any aluminium alloy, at temperatures above the solidus, normally occurs in the brittle temperature range between the temperature at which a coherent dendrite structure is first formed in the alloy, during cooling from the liquid state, and the effective solidus temperature. Because of the presence of liquid between the solid crystals of the mass, an alloy in the brittle temperature range has low strength and no ductility, and cracking is a result of restraint of free contraction while the alloy is cooling through this temperature range. It was suggested that the inherent tendency of an alloy to cracking at temperatures above the solidus—termed by Pumphrey and Jennings the Shrinkage–Brittleness of the alloy—is directly proportional to the extent of the brittle range and to the contraction that occurs during cooling through this range, and is independent of all external factors except those which alter the extent of the brittle range.

8 Pumphrey, W. I. and Jennings, P. H., *J. Inst. Metals*, 1948, **75**, 203.
9 Pumphrey, W. I., and Jennings, P. H., *J. Inst. Metals*, 1948, **75**, 235.

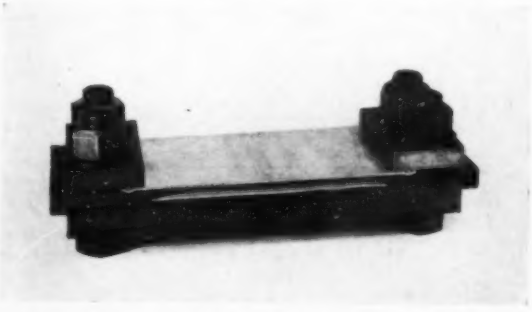


Fig. 5a.—Jig used for restrained weld tests.

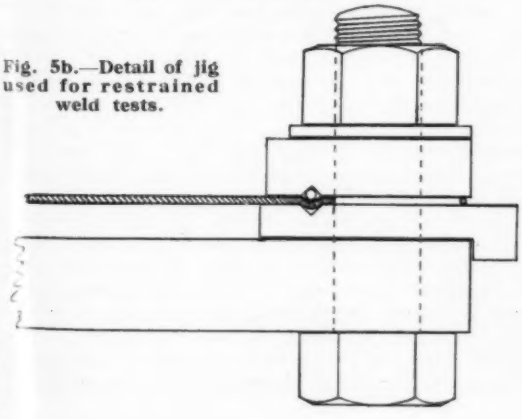


Fig. 5b.—Detail of jig used for restrained weld tests.

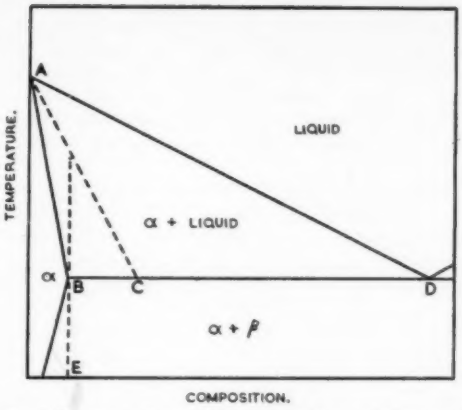


Fig. 6a.—Corner of a schematic phase diagram for a binary alloy system containing a eutectic.

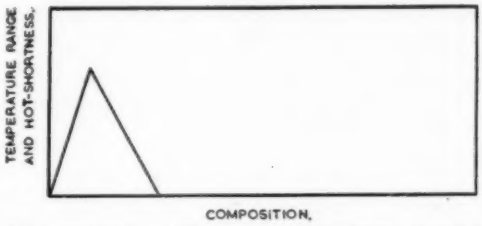


Fig. 6b.—Variation of hot-short temperature range with composition, derived from Fig. 6a.

Factors Influencing Cracking

Pumphrey and Jennings postulated that the extent of the brittle range is influenced by any factor which modifies the course of solidification. The extent of the range is primarily determined by the constitution of the alloy in the relevant conditions but is also dependent upon the amount and mode of distribution of the eutectic liquid within the mass. A minimum shrinkage-brittleness in any eutectiferous alloy is associated with conditions in which there is no tendency for entrapment of liquid between the growing dendrite arms, and when, in consequence, all the eutectic in the finally solidified alloy is situated at the crystal boundaries. The degree to which liquid is entrapped between the dendrite arms during their growth is a function of the linear rate of crystal growth, which in turn is principally dependent upon such factors as rate of cooling and the number of crystal nuclei in the solidifying mass, although secondary factors, such as the gas content of the alloy and the effect of alloying additions on the dendrite configuration, are also of importance.

In the absence of eutectic in the alloy, as in aluminium-zinc alloys containing less than 20% zinc which, as cast, consist wholly of α solid solution, or when the eutectic present is not normal in type, as in certain aluminium-manganese alloys, other factors, such as the crystal size and the micro-structure of the alloy, determine the occurence or otherwise of cracking during casting and welding[10].

The relation between the shrinkage-brittleness and the actual severity of cracking in particular circumstances—this latter quantity was termed the rimosity by Pumphrey and Jennings—is dependent upon a number of factors, notably upon the way in which the severity of cracking is measured, and there is, for any test designed to determine the tendency of alloys to crack during casting and welding, a characteristic curve relating shrinkage-brittleness and rimosity, the precise form of which depends upon the sensitivity of the test. The relationship between shrinkage-brittleness and rimosity may be modified in some measure, if the alloy is capable of accommodating the restraint of the contraction during cooling through the brittle range by a process involving minor adjustments in the relative positions of the crystals. The rimosity is also dependent upon the external stresses to which the solidifying metal is subjected and upon the size and shape of the cracks which occur in the mass.

Value of the Testing Procedure

Throughout the present work considerable use has been made of the ring casting and restrained welding tests for estimating the susceptibility of aluminium alloys to crack at temperatures above the solidus during casting and welding, and it is appropriate at this point to consider the opinions of other investigators regarding the advantages and disadvantages of the two tests.

In the discussion of the paper by Singer and Jennings[7], in which a description of the ring casting and restrained welding tests was given, a number of criticisms of the tests were made. In the first instance, it was suggested that measurement of the total volume of the cracks occurring in a ring casting or weld in any particular alloy would give a more correct indication of the susceptibility to cracking of that alloy than measurement of the total length of the cracks appearing on all surfaces of the casting or weld. Secondly, it was objected that the reproducibility of the results given by the ring casting test is not good, and that, from the results of the test, an alloy which gave one large complete crack through the section of the ring casting would be classed as having less susceptibility to cracking than an alloy giving a larger number of smaller cracks, whereas, in fact, the presence of one large crack in a casting or weld is far more serious in its effect on the mechanical properties than the presence of a number of smaller cracks. Thirdly, it was objected that the degree of restraint imposed on the solidifying casting or weld in either of the two tests may in no way correspond with the degree of restraint imposed in industrial conditions of casting and welding, and that, in consequence, the results given by the ring casting and restrained welding tests may be of no practical significance. None of these criticisms is entirely valid, however. In the first instance it would be difficult to measure the total volume of the cracks in a casting or weld, whereas it is a simple matter to measure the total length of the cracks appearing on the surface, and, since the length of a crack may be considered to be proportional to its volume, the total length of the cracks appearing on the external surfaces of a casting or weld of any alloy is a reasonable indication of the susceptibility of that alloy to cracking. Measurement of the length of the cracks appearing on the external surfaces of a casting or weld gives, of course, no indication of the occurrence of internal cracks. Examination of a large number of ring castings and welds throughout the course of the present work, however, has indicated that only with certain aluminium-zinc alloys is there any tendency for the occurrence of cracks which are confined to the interior of the casting or weld and which do not extend to the outer surfaces[10]. As regards reproducibility of results, the indication of the susceptibility to cracking of any alloy as given by either test is not a result of one test only but is the mean of the results of a minimum of four tests on that alloy, and, when there is any appreciable difference between the results of each test, of as many as sixteen tests, so that the average of the results provides a good indication of susceptibility to cracking. Again it is found that a ring casting which contains one large crack through its section invariably contains a number of smaller cracks in addition, so that it would be rated as indicating a high susceptibility to cracking. The results of ring casting tests carried out by four different operators at intervals over a period of two years, on a series of aluminium-silicon alloys of high purity, are plotted in Fig. 7. The reproducibility of the form of the curve is good, even though, as might be expected, there are differences in the precise amount of cracking recorded by the different operators for any one alloy. With regard to the third criticism, the results of large-scale patch welding tests carried out in industrial conditions on a number of aluminium alloys of high purity and of commercial purity, have confirmed the value of the ring casting and restrained welding tests for predicting the probable tendency of aluminium alloys to crack when welded in

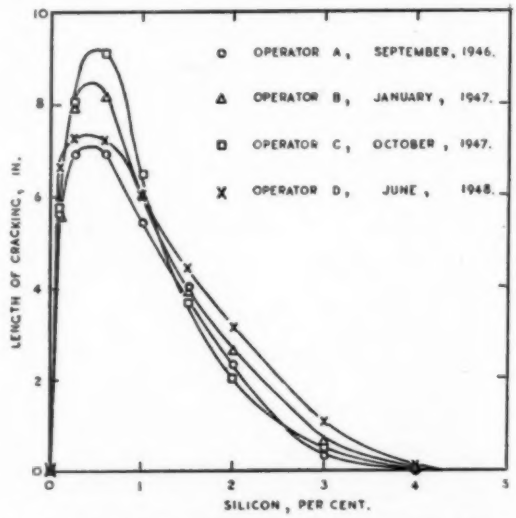


Fig. 7.—Results of ring casting tests carried out by four different operators on aluminium-silicon alloys of high purity.

10 Pumphrey, W. I. and Lyons, J. V., *J. Inst. Metals*, 1948, **74**, 439.

industrial conditions. Both the tests are equally valuable in this respect.

The main advantages of the ring casting and restrained welding tests are, however, that they enable a rapid determination to be made of the susceptibility of any aluminium alloy to crack during casting or welding, and permit of the result being expressed numerically, an advantage which is not possessed by any other test of a similar nature, most of which divide alloys into those which will crack during casting or welding and those which will not.

Survey of Cracking Tendencies

Using the ring casting and restrained welding tests a systematic survey has been made of the tendency to crack, during welding, of aluminium alloys in six binary alloy systems,[10] four ternary systems[11, 12, 13] and one quaternary system[14]. The results obtained with binary aluminium-silicon alloys are shown plotted in Figs. 2 and 3, and the results obtained with alloys of high purity in the aluminium-copper-silicon system, which was typical of the ternary systems examined, are plotted in curve form in Fig. 8[12]. The curves in Figs. 2 and 3 indicate that with aluminium-silicon alloys the maximum susceptibility to crack during welding would be expected in an alloy containing 0·7–0·8% silicon. The contours in Fig. 8 indicate the amount of cracking obtained in restrained welding tests of aluminium-copper-silicon alloys of high purity, and show that maximum susceptibility to cracking would be expected in the ternary alloys of low total alloy content. The curves in Fig. 8 also show that the addition of copper to aluminium-silicon alloys or of silicon to aluminium-copper alloys causes an initial increase in the susceptibility to cracking followed by a gradual decrease. Increase in the silicon content is, however, more effective than increase in the copper content for effecting a reduction in the tendency to cracking of the ternary alloys.

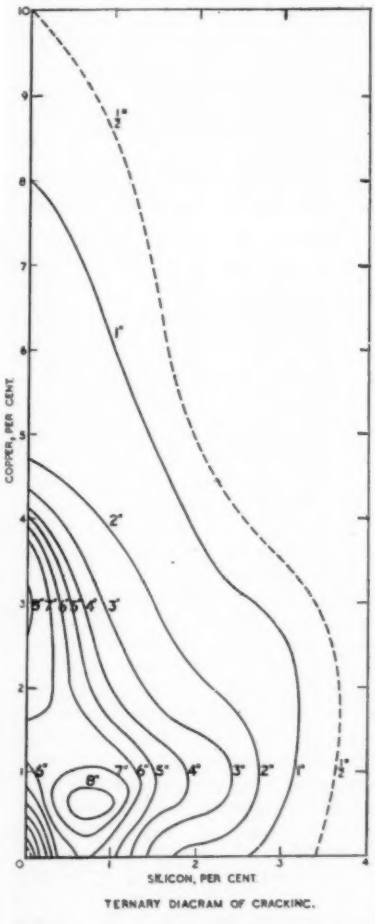


Fig. 8.—The cracking of restrained welds in aluminium-copper-silicon alloys. (Jennings, Singer and Pumphrey).

A limited survey has also been made[15] of the tendency to crack during welding of aluminium-magnesium-silicon-manganese alloys based on specifications D.T.D. 423A and D.T.D. 346, and of aluminium-zinc-magnesium-copper-manganese alloys based on specification D.T.D. 363A and D.T.D. 687.

Methods of Minimising the Cracking Tendency

One method of minimising the occurrence of cracking during the welding of aluminium alloys would be to weld only those alloys which, from the results of ring casting and restrained welding tests, would be expected to have no tendency to crack during welding. The adoption of such a method on a commercial scale would mean alteration of the compositions of many existing industrial alloys and the introduction of new alloys having good welding properties together with reasonable mechanical strength and resistance to corrosion. The most suitable methods for casting, fabricating and heat-treating the existing industrial alloys, and the corrosion, mechanical and other properties of these alloys in the cast or wrought conditions are now known, however, and can be specified with some exactness, and it would take a considerable time to obtain sufficient information to permit similar specifications to be drafted for the development of a new series of alloys even if such a development were commercially desirable. Thus, while the development and introduction into industrial welding practice of a small number of aluminium alloys possessing good welding, tensile and corrosion properties may be advantageous, it would be impracticable to advocate major alterations in the compositions of the majority of existing industrial alloys for the purpose of securing good welding properties. It was therefore considered desirable that the Research Team should concentrate on attempting to improve the welding properties of existing aluminium alloys by some method other than by major alteration of the compositions of the alloys.

Accordingly, a mathematical analysis was made[9] of the conditions which govern the occurrence of cracking at temperatures above the solidus in a straight butt weld between two parallel and restrained sheets of an aluminium alloy, and a relationship formulated which enables an estimate to be made of the manner in which weld cracking is likely to be affected by alteration in the physical properties of the material being welded or by a modification of the welding technique. In particular, this relationship indicates that the likelihood of cracking occurring in such conditions is increased by increase in the extent of the brittle temperature range of the metal in the weld pool, the rate of cooling of the solidifying weld metal, the speed of welding, the degree of restraint imposed on the abutting sheets during the welding operation, the thermal conductivity or the linear coefficient of thermal expansion of the material being welded.

Experimental confirmation of the theoretical suggestions has been obtained in respect of the effect of variation

11 Singer, A. R. E. and Jennings, P. H., *J. Inst. Metals*, 1946, **73**, 273.
12 Jennings, P. H., Singer, A. R. E. and Pumphrey, W. I., *J. Inst. Metals*, 1948, **74**, 227.
13 Pumphrey, W. I. and Moore, D. C., *J. Inst. Metals*, 1948, **74**, 425.
14 Pumphrey, W. I. and Moore, D. C., *J. Inst. Metals*, 1949, **75**, 727.

15 "The Work of the Welding Research Team at the University of Birmingham," Research Report No. 1, published by the Aluminium Development Association, 1947.

in the first four factors mentioned above. From the practical aspect, however, it would seem that methods designed to effect a decrease in the tendency for weld cracking to occur at temperatures above the solidus by decrease in the rate of cooling of the weld metal, the speed of welding, or the degree of restraint on the weld complex, although of value, are likely to be less satisfactory and efficacious than methods designed to decrease the tendency to weld cracking by effecting a decrease in the extent of the brittle temperature range of the metal in the weld pool. It may, however, be possible, in certain instances, to control all four variables simultaneously.

Decrease in the extent of the brittle temperature range of the metal in the weld pool may be effected by welding the basis metal with a filler rod of the same alloy series as the basis metal but of higher alloy content and possibly containing a small quantity of an element added specifically to reduce the crystal size of the metal in the weld bead. Thus, an aluminium alloy containing 5% copper and a suitable quantity of a grain refining agent has been found to be of value for the general welding of aluminium alloys containing copper as the principal alloying element.

Cracking at Temperatures below the Solidus

As mentioned earlier, cracking in aluminium alloys may occur at temperatures between the liquidus and solidus of the alloy considered, or at temperatures considerably below the solidus in castings and welds in certain alloys cooling under severe restraint. Alloys susceptible to cracking at temperatures above the solidus may not be susceptible to cracking below the solidus, and the converse may also be true. Since the two types of cracking are due to fundamentally different causes it is of importance to differentiate between them and to obtain some understanding of the nature of both types of cracking if methods for minimising their occurrence are to be developed.

Cracking at temperatures below the solidus has been observed, in the present work, in alloys in the systems aluminium-copper-magnesium, aluminium-copper-magnesium-silicon and aluminium-zinc-magnesium, and by Lees[5] in Y alloy and an aluminium-magnesium alloy containing 33% magnesium. A consideration of the nature of brittleness at temperatures below the solidus in castings and welds in aluminium alloys has been made by Pumphrey and Moore[16]. These workers suggested that the occurrence or otherwise of cracking in an aluminium alloy, at temperatures below the solidus, is dependent upon the ductility of the alloy and upon the conditions of stress to which the metal is exposed during cooling after casting or welding. The ductility of the alloy is dependent to some extent upon the nature and mode of occurrence of the intermetallic compounds. If these compounds are brittle in nature and occur at the crystal boundaries, then, even if the alloy is not normally subject to cracking at temperatures above the solidus it may, under severe conditions of restraint, crack at temperatures of the order of 100–200°C. during cooling from the liquid state. Cracking may occur at temperatures both above and below the solidus in the same alloy and fine cracks formed at temperatures above the solidus may, because of their stress raising effect, initiate cracking at temperatures below the solidus when the cooling contraction of the metal is restrained. Cracking at temperatures below the solidus does not generally occur in welds made in industrial conditions because of the low stresses to which such welds are normally subjected during their cooling. If such cracking is observed in industrial conditions, however, it is suggested that its occurrence may be minimised by :—

(1) Ensuring that the metal to be welded has adequate ductility.
(2) Designing the welded article and the sequence of welding so that contraction of the metal during cooling is not unduly restrained and there are no excessive stress-raising effects.
(3) Reducing the amount of cracking at temperatures above the solidus by control of the several factors already discussed.

The Development of Alloys having good Welding and Mechanical Properties

Although the welding properties of existing aluminium alloys may be improved by the methods discussed above it is of importance, as already mentioned, to develop a small number of " welding-quality " aluminium alloys which are inherently strong and are especially suitable for welding. To this end a somewhat limited investigation has been made of the tensile properties of selected alloys which, on the basis of ring casting and restrained welding tests have been found to have good welding properties. In this investigation an examination has been made of the welding and tensile properties of a number of alloys in the systems aluminium-copper-silicon[12] and aluminium-copper-magnesium[16], and of alloys based on specification D.T.D. 423A and 346[15]. This work is continuing, but from the limited number of results already obtained it would seem that for applications where reasonably high strength in the heat-treated condition and moderate welding properties are required, an aluminium-copper-silicon alloy containing 4% copper and 1·5% silicon should give satisfactory results. When good welding properties are the first consideration, but moderate strength is also desirable, an alloy containing 2% copper and 4% silicon, or alloys intermediate between this and the previous alloy, should be of value. The welding and tensile properties

16 Pumphrey, W. I. and Moore, D. C., *J. Inst. Metals*, 1948, **75**, 257.

TABLE I.—MECHANICAL PROPERTIES OF ALUMINIUM-COPPER-SILICON ALLOYS

Nominal Composition		Results of tests on annealed material				Results of tests on heat-treated material			
Cu %	Si %	U.T.S. tons/sq. in.	0·1% proof stress tons/sq. in.	Elongation %*	Hardness D.P.H.	U.T.S. tons/sq. in.	0·1% proof stress tons/sq. in.	Elongation %*	Hardness D.P.H.
0	4	6·7	2·1	24·5	30	9·5	4·5	20	53
8	0	8·85	2·5	18·5	39·5	25·6	14·4	12	122·5
2	3	10·0	2·4	22·5	41	14·5	6·25	16	75
2	4	9·2	2·6	22·5	40	15·0	7·55	16	75
4	1·5	9·2	2·65	26·5	39	24·5	14·5	9·5	124·5
6	2	10·4	2·8	24	43·5	26·1	16·5	13	128

* % Elongation on 2 in.

TABLE II.—MECHANICAL PROPERTIES OF WELDS IN ALUMINIUM-COPPER-SILICON ALLOYS

Nominal Composition		Results of tests on welds made in annealed material				Results of tests on welds made in heat-treated material			
Cu %	Si %	Average length of cracking in restrained weld test. In.	U.T.S. tons/sq. in.	Elongation %*	Position of fracture	Average length of cracking in restrained weld test. In.	U.T.S. tons/sq. in.	Elongation %*	Position of fracture
0	4	0·2	6·6	18·5	In basis metal†	0·3	8·0	14	In basis metal.
8	0	1·0	10·1	10·5	In basis metal	1·1	13·25	5	In weld.
2	3	1·2	10·1	9	In weld	1·0	10·8	10	In weld.
2	4	0·05	10·9	13	In basis metal	0·1	11·4	8	In weld or weld area.
4	1·5	1·4	10·3	11·5	In basis metal	1·4	12·25	6·5	In weld.
6	2	0·05	10·1	6	In basis metal	0·2	10·9	3	In weld or at edge of weld.

* % Elongation on 2 in.
† In basis metal indicates that fracture occurred at a point remote from the heat-affected zone of the weld.

of a number of aluminium-copper-silicon alloys of high purity are recorded in Tables I and II[12].

While the two main requirements of a "welding-quality" alloy are that it should be readily weldable and should have good mechanical properties both before and after welding such an alloy must also possess a number of other desirable attributes. Thus, for example, it must be relatively resistant to corrosion and be easy to roll and heat treat. In the development of aluminium alloys suitable for welding, therefore, it is important that the alloys selected on the basis of the results of ring casting, restrained welding and tensile tests should be considered from these other aspects also.

Conclusions

The theoretical treatment of the problem of cracking at temperatures above and below the solidus, developed during the present investigation, is applicable to cracking which occurs in any aluminium alloy during casting and during gas welding and may be utilised to effect a solution to the problem of cracking during either process. It should be emphasised, however, that cracking at temperatures either above or below the solidus is but one of the problems associated with the welding of aluminium and its alloys. While the results obtained in the present investigation may enable the development of a practical solution to the problem of cracking during welding, a complete solution to the welding problem will necessitate an investigation of such other problems as the factors which determine the extent of the heat-affected zone in a weld in any aluminium alloy, and the effect of the welding process, whether gas, arc or argon-arc, on the behaviour of an aluminium alloy during welding and on its properties after welding. Problems of this nature are now under investigation by the Team and it is hoped that their solution will facilitate the solution of the welding problem as a whole.

Acknowledgments

The author wishes to record his indebtedness to the Aluminium Development Association for permission to publish this paper.

Symposium on Metallurgical Uses of the Electron Microscope

THE Institute of Metals is organising an all-day Symposium on "Metallurgical Applications of the Electron Microscope," which will be held at the Royal Institution, Albermarle Street, London, S.W.1., on Wednesday, November 16th, 1949, commencing at 10-0 a.m. The following societies are associated with the Institute in arranging this meeting: the Chemical Society; Faraday Society; Electron Microscope Group of the Institute of Physics; Institution of Electrical Engineers; Iron and Steel Institute; Physical Society, and Royal Microscopical Society. A list of papers to be presented is given below:

ALLEN, N. P. (National Physical Laboratory): "The Application of the Electron Microscope in Metallography" (Introductory Paper).

BAILEY, G. L. J. and S. VERNON-SMITH (British Non-Ferrous Metals Research Association): "The Application of the Electron Microscope in Routine Metallography."

BROWN, A. F. (Cavendish Laboratory, Cambridge): "Elementary Slip Processes in Aluminium as Shown by the Electron Microscope."

BUCKNELL, G. L. and G. A. GEACH (Associated Electrical Industries Research Laboratory): "Some Observations on the Age-Hardening Process in an Aluminium-Copper Alloy."

COOPER, B. S. and G. A. BASSETT (Research Laboratories, General Electric Co., Ltd.): "Studies in the Electron Microscopy of Nickel-Chromium Alloys."

GRIVET, Professor P. (Sorbonne, Paris): "Electron Microscopy in Metallurgy."

KELLER, F. (Aluminium Company of America): "Electron Microscopy of Light Metal Alloys."

MAHL, H. (Süddeutsche Laboratorien G.m.b.H.): "Electron Microscopical Work on Metallurgical Problems in Germany During and Since the War."

MORLEY, J. I. (Firth-Brown Research Laboratories): "A Note on the Examination of Metal Powders by the Electron Microscope."

NUTTING, J. (British Iron and Steel Research Association) and V. E. COSSLETT (Cavendish Laboratory, Cambridge): "A Replica Technique for the Examination of Fracture Surfaces with the Electron Microscope."

NUTTING, J. (British Iron and Steel Research Association) and V. E. COSSLETT (Cavendish Laboratory, Cambridge): "The Dry Stripping of Formvar Replicas from Etched Metal Surfaces."

TROTTER, J., D. MCLEAN and C. J. B. CLEWS (National Physical Laboratory): "The Microstructure of a Water-Quenched Carburised Iron."

The Measurement and Characteristics of Casting Fluidity

By V. Kondic, B.Sc., Ph.D.

The question of the fluidity of molten metals has been extensively studied in recent years in connection with the production of castings. In reviewing the present position the author indicates the factors on which measurements of fluidity depend and suggests that two tests should be developed, to determine the metal fluidity or flowing power, and the ability to fill a mould, respectively.

THE term fluidity has been, and is still, used to designate two different properties of liquids. By the first and older definition the fluidity is the reciprocal of the viscosity, which is a well defined physical property. By the second definition, which is mainly used by foundrymen and metallurgists in reference to liquid metals, fluidity is " the ability of metal to flow "[1], or " that property of metal which allows it to flow freely and evenly into a mould "[2]. The difficulties arising from the differences in physical and metallurgical definitions can be removed by referring to the former fluidity as the absolute fluidity, and to the latter as the casting fluidity. Other terms which have been suggested to replace the term casting fluidity—for example, flowing power, flowability, castability—have not so far been widely accepted.

Origin of the Concept : " Casting Fluidity."

The primary observations that liquid metals or alloys differ in their casting fluidity were obtained through practical experiences arising in the production of sand castings. If one and the same mould is filled by two different alloys, under otherwise identical conditions, then it may happen that with one alloy the casting produced is satisfactory, whilst with the other alloy the casting may show one or more of the following defects : (a) misruns and cold shuts resulting from incomplete filling of the mould, (b) internal unsoundness caused by inadequate feeding during solidification of the casting, (c) rough surfaces, usually caused by the turbulent filling of the mould. Similarly it has been observed that alloys may differ in their behaviour when flowing through the small apertures which usually form part of the mould gating system. Finally, one alloy may be used at a lower superheat temperature than the alternative alloy to give a casting of the same " quality ". On the basis of these and other observations it has been assumed that such differences in behaviour of different alloys may be due to the differences in their respective casting fluidities, which are, everything else being the same, intrinsic properties of each alloy composition. Three major problems were created by this assumption : (a) Can such a " property " be measured by a suitable test other than that of making an actual casting ? (b) Which combined properties of the liquid alloy and the mould into which it is poured determine the value of the casting fluidity ? (c) How far and when does this " property " affect the quality of the finished casting ?

These three major problems, as well as a number of subsidiary ones dealing with fluidity, have been fairly extensively studied. Several theories resulting from such work have provided satisfactory answers to some of the problems. Further experimental and theoretical work is, however, still required, not only to explain the remaining unresolved questions, but also to remove certain controversies which exist in the present theories. The object of this paper is to review the present position in this field.

Measurement of Casting Fluidity

Arising from the definition, the first attempts at measuring the casting fluidity were based essentially on the principle of using a mould with a suitable channel through which the liquid metal flows until it solidifies, and measuring the length of the resultant casting as an index of the casting fluidity. The numerous designs for such moulds and pouring devices for filling the mould, suggested and used by different workers, have recently been reviewed by Clark[1]. The main trend in the developments in methods of casting fluidity measurement has been towards standardising the casting and experimental conditions with the object of obtaining a higher degree of reproducibility and accuracy of results. It can be seen from the schematic drawing, Fig. 1, that the main variables in the design of a fluidity testing apparatus are the size and shape of the fluidity channel, the hydrostatic pressure H, and the method of joining the pouring basin with the fluidity channel.

Basing his arguments on previously published work, Clark suggested a number of numerical values for the

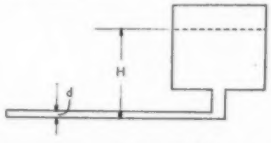


Fig. 1.—Schematic sketch of fluidity testing apparatus.

dimensions of the fluidity apparatus, as well as certain principles of design to guide future workers in this field, in order to obtain a certain degree of standardisation and correlation. It is doubtful, however, whether any such standardisation is likely to be widely accepted before further fundamental data necessary for the interpretation of casting fluidity are available.

It is apparent from the examination of the experimental data available, that the definition of casting fluidity (as given in the introduction) is not sufficiently precise to be used as a basis for devising a method for its measurement. In effect, the condition of the first metallurgical definition can be met by numerous alloys having the same fluidity, as obtained by the present methods of testing, although they might all differ in their behaviour when filling a mould. In other words, mould filling ability is a function of a number of factors, amongst which the casting fluidity, as defined by the first definition, is but one. Such factors are : mould material, temperature, design, surface, atmosphere and methods of gating. If, on the other hand, the second definition of the casting fluidity is used as a basis of

1 " Fluidity Testing of Foundry Alloys," Clark, K. L., *Proceedings Institute of British Foundrymen*, 1945–6, **39**, A.52.
2 " Fluidity of Metals," Briggs, C. W., Metals Handbook, 1948, 199.

comparing the "fluidity" amongst different alloys, then the values obtained by such a test may be affected by the mould variables to such an extent that little or no information is obtained on the actual "ability to flow" of the liquid metal. This is mainly controlled by such metal variables as solidification characteristics, and thermal, chemical and physical properties of the metal. It is, therefore, impossible to devise a fluidity test which will be at the same time very sensitive to mould as well as to metal variables . (In this respect the metallurgical problem of fluidity testing is similar to the problem of casting and standardisation of test bars. It is now generally agreed that test bars as used nowadays are not at the same time an index of the metal quality as well as an index of the quality of the casting at each section). One possible solution of the fluidity problem is that of defining the casting fluidity as the ability of the metal to fill the mould and give satisfactory castings, and use the term metal fluidity, or flowing power, to define the ability of the metal to flow under a falling temperature gradient. If these changes in definitions were accepted, then it would be a comparatively simple problem to devise suitable methods for testing each of these two complex properties. The casting fluidity test would be used to provide such data as are of direct application in comparing "mould filling abilities" of different alloys. The metal fluidity test would be, on the other hand, more suitable for studying the nature of liquid metal flow and properties of the liquid state which are of general metallurgical, as well as of industrial, interest. There are further advantages of such a modification in the definitions of casting fluidity : (a) it would be possible to express the value of the metal fluidity, or flowing power, in terms of certain standard physical constants and (b) the value of the casting fluidity and metal fluidity could be correlated for any specific set of casting conditions.

Before dealing with the requirements of tests which could be used for measuring casting fluidity and metal fluidity respectively, the main characteristics and interpretation of results obtained by the present method of casting fluidity measurement, are briefly reviewed.

Characteristics and Interpretations of the Casting Fluidity obtained by the present Method of Measurement.

In the casting fluidity test normally carried out, molten metal is poured, at a desired temperature of superheat, into a sand or a metal mould and left there to solidify. Although different types of moulds, pouring methods and a great deal of control variation in carrying out such tests have been reported, a number of general observations have been made.

The "casting fluidity" value, i.e., the length of the fluidity test specimen (this is usually cast in a spiral form) is affected by both mould and metal properties. It is interesting to note that mould variables have so far been comparatively little studied. Whilst it has been reported that such factors as, for example, mould surface, or the type of dressing, affect the casting fluidity, only a small amount of quantitative data on the effects of these or other mould factors is available. The following are some important points that have been observed in this field.

The changes in the length of the fluidity test piece, produced by the variation in the mould surface, are largely controlled by the surface properties of the liquid alloy. Alloys that form tenacious or brittle oxide films on exposure to the air, are more sensitive to the type of mould surface than alloys that do not form such films. It is believed that the type of mould has a determining effect whether oxide films are retained unbroken at the mould surface or are continuously torn away, thus giving rise to turbulent flow and short lengths of the fluidity test piece.

The dimensions of the fluidity mould channel and methods of casting the test piece are chosen in such a way that a suitable length of the test specimen is obtained and so that casting conditions are readily reproducible. The dimensions of the fluidity channel can be related to the length of the cast test specimen by the thermodynamic consideration of the problem of heat transfer from the molten metal to the mould. Working on this basis, Bastien[3] obtained the relationship.

$$\lambda = \alpha \frac{dc\ (\theta - t_1)}{t_1 - t_2} + \beta \frac{Ld}{t_1 - t_2}$$

where :

λ = spiral length, d density of the metal,
c = specific heat, θ = pouring temperature,
t_1 = solidus temperature, t_2 = mould temperature,
L = heat of fusion, and α and β are constants.

This equation relates such variables as the fluidity length, and the metal and mould temperatures. These relationships are shown in Fig. 2. The general nature of these graphs has been confirmed experimentally. It was shown, however, that there may be considerable deviations from these graphs at temperatures close to the melting point[4].

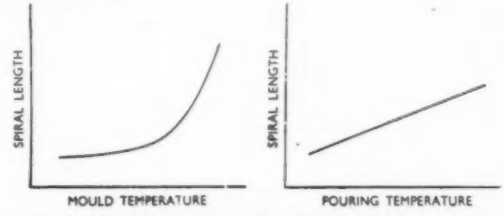


Fig. 2.—Curves showing relationship between spiral length and metal and mould temperatures.

The influence of the hydrostatic head on the resultant length of the fluidity specimen is a characteristic property of each fluidity apparatus. It appears that there is for every set of casting conditions a range of values of hydrostatic pressure in which the length of the fluidity test specimen is little affected by small variations in the hydrostatic casting pressure[4].

The effect of the metal properties on the resultant length of the fluidity test specimen has been studied more extensively and the experimental work in this field has also been more fruitful. Several valuable generalisations have been obtained, but a number of unresolved problems still remain. The important properties of the liquid metal controlling its casting fluidity are : thermal properties, viscosity and surface properties.

One of the essential features of the fluidity test is that of continuous cooling during the metal flow. The length of the test specimen, as shown by Bastien and others, is "dependent on available heat of molten plus the heat of solidification." When the fluidity of different metals is compared, under standard experimental conditions, then the sequence of increasing fluidity is in many cases

3 "Fluidity of Metals and Binary Alloys," Bastien, P., *Revue de Metallurgie*, 1934, **31**, 270.
4 "Fundamental Characteristics of Casting Fluidity," Kondic V. and Kozlowski, H. J., *Journal of the Institute of Metals*, 1949, **75**, 665.

that of increasing available heat content. In certain cases, however, the effect of either viscosity or surface properties may predominate over the thermal effects.

Controversial views are held about the effect of the metal viscosity on the length of the casting fluidity test specimen. It has been frequently considered that viscosity, as such, plays only a minor part in fluidity testing. On the other hand, there is a certain degree of evidence available that, for certain alloys at least, and under certain conditions of fluidity testing, the viscosity may have an appreciable, if not determining, effect. Modified aluminium-silicon alloys have been found, for example, to have greater viscosity and give correspondingly lower fluidity values than those obtained with unmodified alloys[4, 5].

A relationship which has been found to hold generally for a number of alloy systems is that shown in Fig. 3.

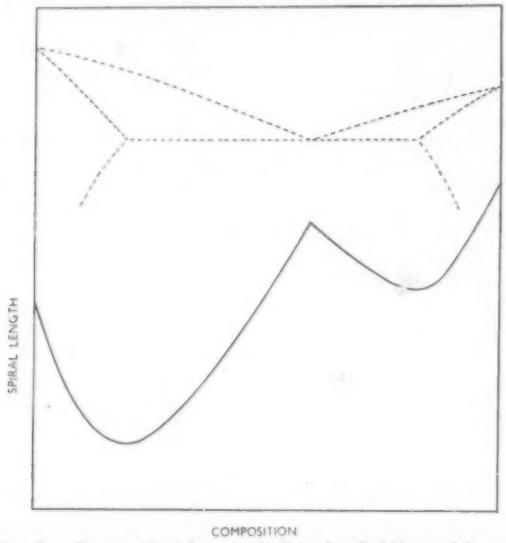


Fig. 3.—Curve showing variation in fluidity with composition for a eutectic system showing limited solid solubility.

This diagram shows that solid solution alloys possess a lower fluidity than either pure metals or eutectic compositions. It has been suggested that this effect can be explained in terms of the mechanical interference, during flow, of crystal dendrites growing from the mould wall. Alloys which solidify over a temperature interval would be most prone to such an interference owing to the characteristic form of dendrites in such alloys. An alternative explanation for the above relationship is based on the assumption that the viscosity changes with composition in a similar way to that shown in Fig. 3, and that this is the primary reason for the fluidity-composition relationship. Additional experimental work is needed, however, to determine the conditions under which either hypothesis is valid, as well as to explain certain anomalies which have been met with in a number of binary alloy systems.

Surface tension, surface oxide films and, in general, surface phenomena that are encountered in liquid flow, have received little theoretical and experimental attention in fluidity testing and this is one of the large gaps in the field. Two general conclusions have however been brought out by experiments: (a) oxide films have an important effect on the casting fluidity, (b) the effect of oxide films varies appreciably with the conditions of testing.

5 "Viscosity of Metals," Polyak, E. V. and Sergeev, S. V., *Compt. rend.* (Doklady) *Acad. Sci. U.R.S.S.*, 1941, **32**, 244.

Future Developments in Fluidity Testing

Three important applications of fluidity testing in the metallurgical field are: (a) testing the quality and condition of molten metal in the production of castings, (b) following the progress of melting processes in smelting and refining and (c) developing alloys of improved fluidity for special casting applications. These tests are based on the sensitivity of the length of the fluidity test specimen to alloy composition, condition and temperature. In general, it is considered that the data obtained by the present methods of fluidity testing could be used as an indication of the ability of the metal to fill a mould. An analysis of the available data, however, leads to the conclusion that mould filling ability is equally, if not more, affected by mould properties than by metal properties. Yet the tendency of current development in fluidity testing is that of obtaining a test which is more sensitive to metal than mould properties.

One solution of this problem, as already suggested, is that of developing two distinct types of fluidity tests. The first test, i.e.,the casting fluidity test, should be designed to assess the mould filling ability of an alloy. This test should be sensitive to the main properties of a mould: surface condition, thermal properties, gating system and hydrostatic head. The second test, i.e., the metal fluidity or flowing power test should be more sensitive to the liquid metal properties, and would be carried out under standard and specified mould conditions.

Experimentally, either test is likely to develop by further refinements of the currently used fluidity test. The essential feature of the casting fluidity apparatus should be that of attaining similarity to the casting conditions when filling a mould. On the other hand, the metal fluidity, or flowing power, test should be carried out under conditions which are conducive to detecting slight changes in the ability of the metal to flow.

Record Production by the United Steel Companies Limited

DURING the year which ended on June 30, 1949, the firm made more than 2 million tons of steel ingots for the first time in its history. The actual figure was 2,042,056 tons which is 146,000 tons better than the record made last year. This is a record in more than one sense as no other British steel firm has ever made as much.

A number of other records were broken too. The Appleby-Frodingham Branch at Scunthorpe made 830,000 tons of steel ingots, and the Steel, Peech and Tozer Branch at Rotherham made 761,000 tons. It is believed that no other British steelworks has made as much as either of these. Both these branches and the Samuel Fox and Company Limited branch at Stocksbridge beat their previous records by substantial margins.

The cogging mill at Steel, Peech and Tozer, rolled almost 800,000 tons which beat its last year's record by 82,000 tons. It is believed that this is a record for any one cogging mill in this country. The Templeborough melting shop at this branch alone made 573,000 tons of ingots and maintained its position as the largest melting shop in the country.

Electric Furnaces in the Metal Industries

By G. Reginald Bashforth, F.I.M.

The story of electric furnaces in the metal industries is one of steady progress and expansion. In the years immediately prior to the War, their introduction into the industry, both for melting and heat-treatment purposes, had been rapid. During the War, in order to meet the increased demands for special steels and alloys and the more precise treatment of many products, their development was greatly accelerated. At present, owing to power supply difficultes, the installation of new plant is slow and uncertain. In this first article the author deals with the various types of arc furnaces and reference is made to the electric reduction furnace.

THE many advantages which electric furnaces offer both for the melting of metals and for their heat-treatment, assure the future adoption of this type of furnace in many spheres. The cleanliness of application and the ease with which they can be regulated recommend them for many purposes.

As melting furnaces, they permit the reduction of melting losses to a minimum and allow metals to be melted without contamination by the impurities present in other types of fuel. The ease with which temperature and atmosphere can be controlled presents distinct advantages in the field of heat-treatment. The chief obstacle is the cost of operation.

The conversion of electrical energy into heat can be accomplished in two ways :—

1. By means of an arc, which produces a concentrated source of heat at a high temperature ; the temperature of the electric arc is over 3,000° C. In the case of the arc the current flows through an indeterminate conductor, the resistance of which produces heat. This indeterminate conductor consists of vapour between the electrodes.
2. By means of resistance through a definite conductor. In this type of furnace the conductor may be the charge to be melted, as in induction furnaces, or a specific resistance element or elements, which radiate the heat produced by the resistance to the passage of the current.

In both cases the heat is produced by the resistance of a conductor to the passage of current. According to Ohms law :—

$$V = IR$$

where V = volts (pressure)
I = amps (current)
R = ohms (resistance)

The power expended in overcoming resistance equals the square of the current multiplied by the resistance, or

$$P = I^2R$$

From these electrical formulae the heat units produced can be calculated on the basis that one Kilowatt hour (kWh.) is equal to 860 Kilogramme calories or 3,412 B.T.U. The heat produced in any circuit is expressed by the formula :

$$H = \frac{I^2 R.t.}{1{,}000}$$

where H = heat produced in Kilowatt hours.
I = current in amps.
R = resistance in ohms.
t = the time, in hours, during which the current is flowing.

On the basis of the thermal equivalents given above, this formula can be expressed :—

$H = 0{\cdot}86\ I^2\ R.t.$, Kg.-cals.
or $H = 3{\cdot}412\ I^2\ R.t.$, B.T.U.

These expressions enable the amount of power required to perform a given task to be calculated. The theoretical amount of heat required to melt any metal is the sum of the latent heat and the sensible heat. The sensible heat is the specific heat of the metal multiplied by the temperature increment. The theoretical amount of electric power to melt one ton of steel at 1,600° C. or 2,730° F. is, therefore :—

Sensible heat $0{\cdot}162 \times (2{,}730-60) \times 2{,}240 = 970{,}000$ B.T.U.
Latent heat of fusion $= 195{,}000$ B.T.U.
Total heat required $1{,}165{,}000$ B.T.U.

that is $\frac{1{,}165{,}000}{3{,}412} = 342$ kWh.

In a similar way the theoretical amount of power required to melt any weight of any substance can be calculated from the latent heat and specific heat of that substance, the weight of substance involved and the temperature increment necessary to effect fusion.

The theoretical amount of power necessary to heat a substance to a definite temperature is a more simple calculation. In this case the heat required is the product of the weight of substance involved, the temperature increment required and the specific heat of the substance. The total heat requirement divided by 3,412 represents the theoretical electric power necessary in kWh.

In practice, however, electrical heating does not give 100% efficiency. There are various losses due to radiation and electrical phenomena. In some forms of application these electrical losses may be considerable, especially if not corrected.

ARC FURNACES

Indirect Arc Type

Arc furnaces can be divided into two types :—

1. Indirect or Arc Radiation Furnaces.
2. Direct or Arc Resistance Furnaces.

In the case of the *indirect* or *arc radiation furnace*, the heat is generated by an arc formed between two electrodes placed above the charge. This heat is transferred to the charge by direct radiation and by reflection from the furnace lining.

The furnace usually consists of a cylindrical steel shell, through the axis of which two graphite electrodes enter the furnace chamber. This steel shell is lined with suitable refractory materials, which may be acid, basic, or neutral, according to the process being employed. It is obvious that the life of these linings is of a low order, owing to their exposure to the radiant heat and the reflection of that heat to the charge. The shell, however, is usually designed to rock or rotate, and this rotation of the bath considerably prolongs the life of the refractory lining. The rotation of the shell also assists the transfer of heat. The movement brings the charge into direct contact with the hot lining and thereby heat is transferred by conduction.

This type of furnace is supplied in various sizes, ranging from 40 to 3,000 lbs. in capacity, although larger furnaces have been installed. Normally they are employed for the melting of non-ferrous metals and alloys, but they have also a limited use in connection with ferrous metals which do not require high temperatures. The development of special refined irons has made considerable demands on the indirect arc furnace, which offers an excellent melting medium for this class of alloy. Furnaces of this type are also employed in the iron foundry for the production of the ordinary grades of cast iron from cheap raw materials. It is possible to convert cheap scrap, even borings and turnings, into high quality low duty irons at a very economic rate. In some cases the cold materials are charged and melted in the usual way, and after any necessary refining or additions the whole charge is tapped. At other plants a semi-continuous process is employed; after tapping off a certain quanity of metal to meet immediate requirements, the remainder of the molten metal is left in the furnace. The charge is then made up to the normal weight by the addition of cold stock and melting proceeds in the usual manner.

This type of furnace presents several advantages for foundry and similar applications, namely :—

1. A more regular supply of hot metal is available, which permits more continuous operation in the casting bay.
2. A more accurate control of metal temperature, thereby eliminating many foundry difficulties.
3. In foundries manufacturing a wide range of specifications several grades can be produced by suitable alloy additions to one metal base. This alloy requirement can frequently be made by the use of scrap metal of known composition.
4. A cold furnace can be started up with cold materials and the charge is ready for tapping within two or three hours. This is an obvious advantage in plants working intermittently.
5. The furnace chamber is practically gas-tight, so that oxidation losses can be reduced to a minimum. This feature is of considerable importance when melting expensive materials, or when producing to very close specifications.
6. In works dealing with both ferrous and non-ferrous products, spare bodies, which can be quickly changed, can be kept at hand. This enables the employment of different types of lining according to the metal being used.
7. The rotation of the furnace tends to produce a more uniform product.

Against these advantages, however, must be set the increased capital cost of the plant, including electrical equipment, the slightly higher cost of the lining and the cost of power and electrodes. In many cases, however, these higher costs are easily offset by the advantages enumerated.

Robiette[1] shows that it is possible to melt a charge of brass in twenty to twenty-five minutes, with a power consumption of 280 to 300 units per ton. This is approximately half the power required for melting cast-iron. The refractory costs shown are very low, and when compared with the melting of brass in a crucible furnace, a saving of 25% in the total melting cost is demonstrated. The melting losses are also considerably reduced and this feature is important in the economics of the process.

One particular foundry claims that the installation of an electric furnace has resulted in a considerable reduction in the number of castings rejected. This reduction of defectives is attributed to more accurate control of both the melting practice and the heat required for teeming.

It would appear that this type of furnace is eminently suitable for the production of a wide range of metals and alloys, including brass, bronze, copper and copper alloys, bearing metals, nickel alloys and special cast irons. Under certain conditions it is a very attractive proposition for foundry work.

Direct Arc Type

Most of the *direct* or *arc resistance furnaces* now in operation are a development of the Heroult furnace (Fig. 1). In this type of furnace, heat is generated by arcs formed between the electrodes and the bath, and by the resistance of the metallic bath to the passage of the current. These furnaces vary in size from 3 to 40 tons, although furnaces up to 80 and 100 tons capacity have been installed in America. It has been found, however, that steel produced in the larger furnaces in America has not been able to command such a high price as steel produced in smaller capacity furnaces. This is probably due to overheating in the vicinity of the arcs, which is apparently necessary in order to generate sufficient heat throughout the bath. A popular size for special steel production appears to range from 15 to 35 tons.

Actually direct arc furnaces should be divided into two classes—the conductive and the non-conductive hearth type. The *conductive hearth* type, which was developed from the Girod furnace (Fig. 2), has one or more electrodes embedded in the hearth in addition to the electrodes which enter through the roof. In this type of furnace the current passes through the upper electrodes forming an arc with the charge, and through the charge to the lower or hearth electrode or terminal. It has been

1 Robiette, *Foundry Trade Jnl.*, Feb. 27th, 1936.

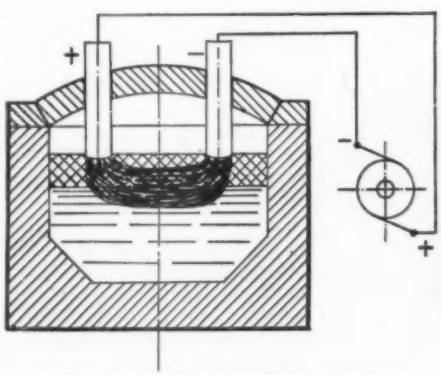


Fig. 1.—Section of a Heroult arc furnace.

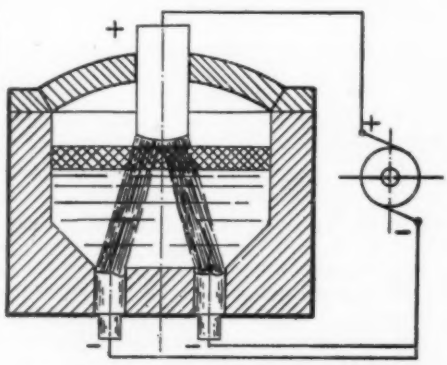


Fig. 2—Section of a Girod conductive hearth furnace.

claimed that this type of furnace offers a better heat distribution, but it has been largely superseded by the non-conductive hearth furnace.

In the *non-conductive hearth furnace* the electrodes enter the furnace through the roof and there are no electrodes embedded in the hearth. It is this type of furnace which has been adopted on a large scale for the production of special steels and is eminently suitable for steel foundries.

The body of the furnace consists of a steel shell lined with suitable refractory materials. The electrodes enter the furnace through the roof, which is usually moveable to permit top charging. The introduction of the removable roof has considerably increased the speed of charging. Although first patented in 1925, the removable roof was not developed until 1932, since when it has become almost universal design.

In some cases the roof swings away from the bath so as to allow the whole charge to be put into the furnace by means of a drop-bottom bucket. In other cases the roof slides to one side to allow this method of charging. It has been suggested that towards the end of its useful life the roof becomes weak and some danger may accompany its removal for top charging. This danger is overcome in some designs of the Siemens-Halske furnaces by the provision of a stationary roof and a sliding hearth.

Whichever type of removable roof is adopted, the practice of top or bucket charging has considerably speeded up the process. With a sliding hearth or a removable roof it is possible to charge a 15 to 25 ton furnace in the matter of 5 to 10 minutes. By direct comparison on two 25 ton capacity furnaces in America it is claimed that this method of charging has resulted in 30% increased production, 22% decrease in refractory costs, 15% reduction in electrode consumption whilst

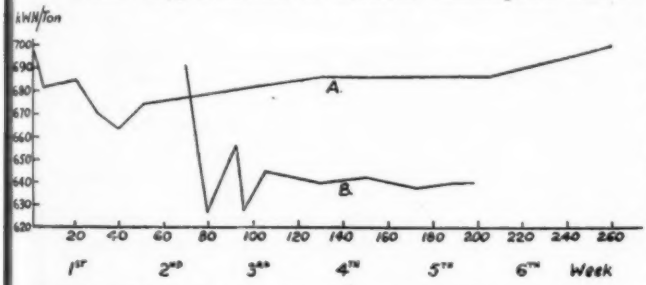


Fig. 3.—Effect of power input on power consumption.
Curve A.—All available power put into the circuit.
Curve B.—Power input reduced.

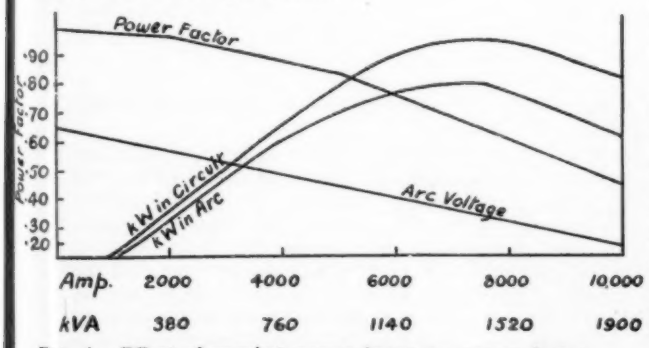


Fig. 4.—Effect of varying power input on power factor and power consumption.

the power consumption was reduced from 670 to 625 kWh. per ton.

The power consumption naturally varies with the size of the furnace and the particular practice employed. In small furnaces melting cold scrap charges the power consumption for actual melting may be as high as 600 kWh. per ton falling to 450 kWh. in the case of larger furnaces Additional power will be required for refining the metal and the amount will depend on the process and the type of steel being produced. When operating a single slag process an additional 150 to 180 kWh. may be sufficient. This figure, however, may rise to 300 or 400 kWh. when producing special transformer steels with very low watt losses

The power consumption is also affected by the method of charging and this aspect has been the subject of many able discussions. C. H. von Baur[2] in an excellent paper on heat transfer showed that when small material was placed on the bottom of the furnace followed by medium pieces in the middle and larger pieces on the top, a very slow melting rate was obtained. The fastest rate of melting and the lowest power consumption were attained when the larger pieces were placed on the bottom with the medium material in the middle and the smaller scrap on the top.

In another series of experiments he investigated the effect of varying the power input. These experiments were conducted on a 2 to 3-ton Héroult furnace producing steel for castings. The furnace was worked on a three phase current at 110 volts per phase—the inherent reactance was 10 to 12% and no choke coil was employed. The transformer was rated at 1,200 kVA.

During the first run which extended over approximately seven and a half weeks, the maximum available power was put into the circuit and the average power consumption for 272 heats was 701 kWh. per ton. These results were probably affected adversely by a high consumption during the last three weeks when the side walls were badly worn thereby allowing excessive radiation losses. The power consumption during the first four and a half weeks of this trial was 685 kWh. per ton.

In the second series of experiments, which extended over a period of three weeks, the power input was reduced considerably and the power consumption decreased to 647 kWh. per ton. These results are shown graphically in Figs. 3 and 4, and they demonstrate that this particular furnace can be operated more economically at 5,000 to 6,000 amperes than at 8,000 to 10,000 amperes. It is, therefore, obvious that the optimum operating conditions must be determined for each particular furnace and/or practice.

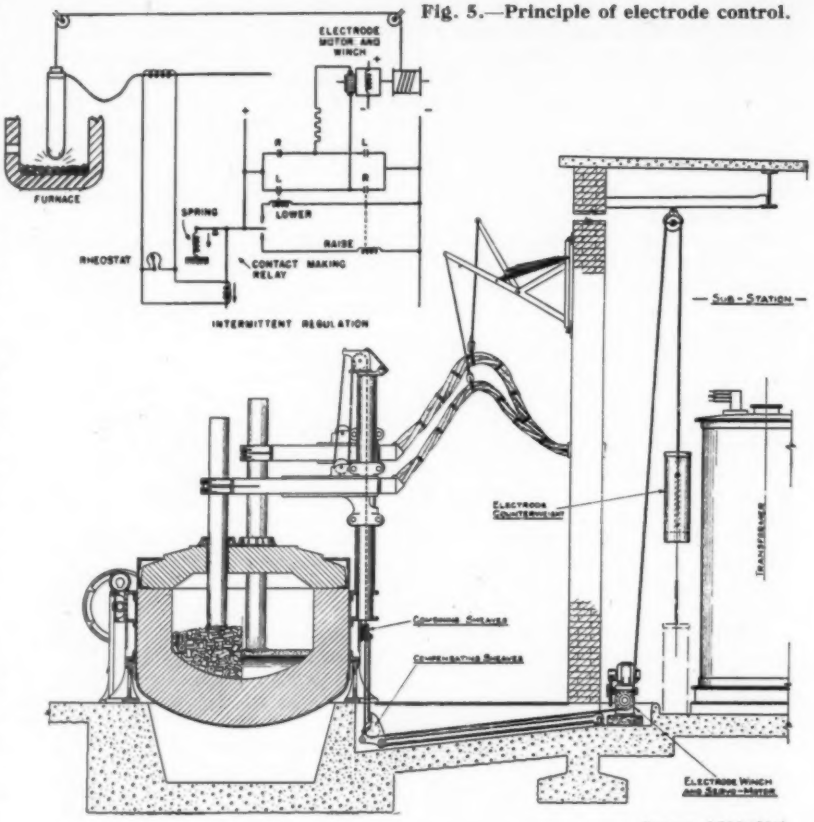
As soon as the furnace is charged and, in the case of top charging, the roof in position, the control of the electrodes can be entirely automatic. The control will look after the striking of the arc, and subsequently maintain the power input at the desired level. Several methods of electrode control have been introduced and the general principles are shown in Fig. 5. The automatic control can be used to vary mechanically, hydraulically or by any other convenient means the position of the electrodes. Fig. 6 illustrates one efficient electromechanical method of applying the automatically controlled power to the electrodes themselves.

2 Von Baur, C. H., *Steel*, May, 1939.

Electrode consumption is an important item in the operational costs and efficient electrode control can considerably reduce breakages, due to the electrodes being forced down on to the charge. The main consumption of electrodes, however, does not always take place at the arcing end. It occurs over the whole area of the electrode within the furnace chamber and up to a point some twelve or fifteen inches above the roof. This consumption is due to the erosion of the electrode by the oxidising flames or fumes ascending and passing through the space between the electrode and the opening in the roof which permits its entry. It is not unusual to find electrodes badly eroded or tapered at this point and several devices have been suggested to reduce this trouble. The most successful devices introduced are those which reduce the possibility of fumes escaping at this point and they usually consist of a water-cooled gland around the electrode, which reduces the space.

The electrodes are usually made of amorphous carbon, although graphite electrodes are frequently employed. When melting steel and electrode consumption varies from 14 to 30 lbs. per ton, the consumption being slightly higher with amorphous carbon than with graphite electrodes, which are, of course, more expensive.

Fig. 5.—Principle of electrode control.



Courtesy of Birlec, Ltd.

Fig. 6.—Birlec " Electromelt " electrode control.

Steel Furnaces

Arc furnaces engaged in the production of steel are normally operated on a basic lining, although some foundries employ acid lined furnaces. Considerable difficulty is experienced in obtaining sufficient materials low in sulphur and phosphorus to operate the acid process on an extensive scale. Where the acid process is employed it generally depends on the low sulphur and phosphorus scrap arising within the particular foundry, whilst the basic process is used for the conversion of the more miscellaneous bought scrap into high grade steel. Owing to the low material cost and the quality of the final product it is possible to operate the basic lined furnace very economically, even for the production of common grades of steel.

When operating the acid process, the body of the furnace is lined with silica bricks and the working hearth is prepared with a siliceous material. The hearth mixture generally consists of silica sand mulled with about 4% of ball sand to act as a bond, and is moistened with a 5% solution of sulphite of lye. An excellent description of the acid arc process for the production of high grade steel castings has recently appeared in the technical press[3].

In the basic arc process a very wide range of steel scrap may be employed and the furnace is lined with basic refractories, with the exception of the roof, which is usually constructed with silica bricks. At some plants the side walls of basic furnaces are built of silica bricks, although most works use magnesite bricks for this purpose. In some cases magnesite bricks have been replaced by stabilised dolomite bricks, which have given very satisfactory results in the side walls.

An extensive investigation has recently been conducted into the construction and performance of electric arc furnace roofs and this has been the subject of a very useful report[4]. The data collected appeared to show that the fixed dome type roof has a longer life than the flat centred movable roof, which frequently failed due to spalling. There are, however, other factors which affect roof life, namely :—1. The type of refractory employed ; 2. The expansion allowance and the rise of the roof ; 3. The rate of initial warming up ; and 4. The power input which affects the temperature attained during melting and refining.

The shell of the hearth is usually bricked with stablised dolomite or magnesite bricks to a thickness of 9 to 12 inches and the working hearth is superimposed on this brickwork. The working hearth may consist of either dolomite or magnesite grains rammed into position and subsequently fritted into a monolithic mass. After ramming, the hearth is dried thoroughly with a coal fire, then filled with coke and the arc struck on the coke in the usual way. The furnace is then brought up to a

3 Steel Castings, *Iron and Steel*, April, 1948.

4 Report on Refractory Materials. I. & S. Inst. Special Report, No. 32, 1946.

sufficiently high temperature to ensure the complete fritting of the lining, which is subsequently slagged. Slagging consists of charging a small quantity of steel turnings, lime and iron ore, and splashing the molten mixture all over the hearth and banks of the furnace.

If a satisfactory working life is to be obtained the hearth must have the correct contour. When the furnace is tilted into the tapping position, the hearth should slope towards the tap-hole. This feature prevents slag or metal collecting in the hearth, thereby exerting a corrosive action during the melting of the subsequent charge.

One of the latest developments in the preparation of the working hearth is the employment of "graphitised dolomite". This material consists of dolomite which has been ground to flour and mixed with about 1% of graphite. The mixture is tramped into position with rammers, and when consolidated, the furnace is charged. During the melting of the first charge the dolomite is sintered into a monolithic mass. Several successful hearths have been installed by this method, which is covered by patent rights.[5]

The charge employed in the electric arc furnace consists entirely of steel scrap, which may be refined by a one-slag or two-slag process. In the one-slag process the metal is refined under an oxidising slag in a manner similar to the basic open hearth process, and when sufficiently refined it is tapped off. With the two-slag process, the metal is first refined under an oxidising slag, which is completely removed before a reducing slag is formed. This reducing slag is usually made up from lime, fluorspar, sand, coke and ferro-silicon, although the actual mixture varies at different works and for the production of different classes of steel. The process enables the manufacture of very high grade steels from comparatively low grade raw materials, and renders possible the production of alloy steels by the reclaiming of alloy steels scrap.

One peculiarity of the arc furnace is the load characteristics. During the melting down of the charge violent fluctuations occur, but when liquid metal has been formed the arcs become more regular and the load characteristics more normal. At this stage about 85% of the peak load is required. During melting a voltage of between 120 and 180 volts is usually carried and this voltage is dropped as refining proceeds, when less heat is required. In the later stages of the process the voltage is frequently dropped to 80 or 100 volts. The total power used during this refining period is usually about 25 to 30% of the peak load, whilst towards the end of the process the load factor maybe as low as 10%.

Since the rate paid for power depends on the load factor it is of considerable importance that it is maintained as high as possible. If two furnaces can be operated in conjunction so that their melting and refining periods are staggered, a much improved load factor can be attained. The effect of this staggering is shown in Fig. 7, taken from a paper by the author[6], where it will be noted that one furnace operated alone gave a load factor of only 63·3%, whilst two furnaces worked together resulted in a load factor of 76%. This factor can be still further improved by staggering the operation of three furnaces.

In arc furnaces continuously at work the distribution of power approximates :—

To the charge	62%
To electrical losses	9%
To heat in the cooling water	4%
To radiation losses, &c.	25%

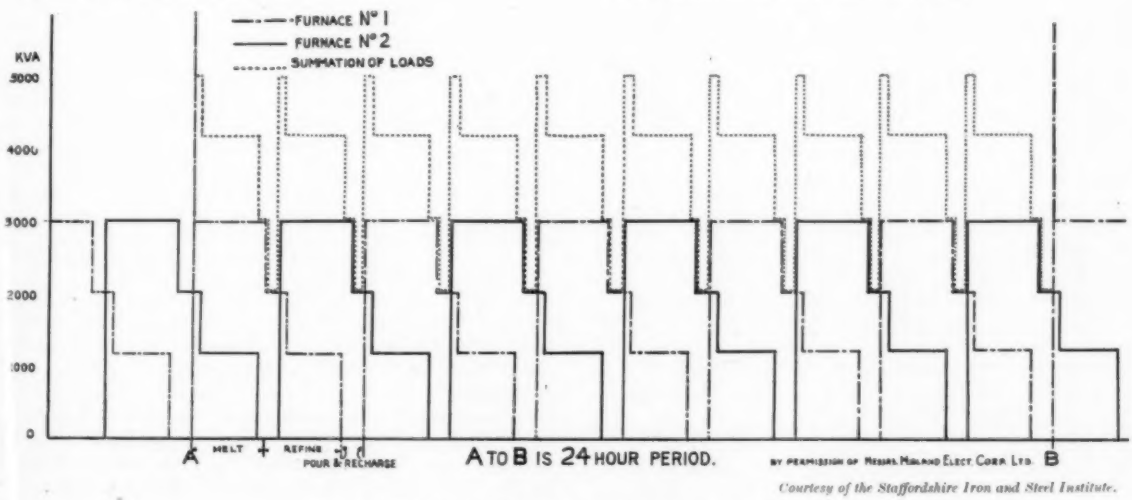
Electric Reduction Furnaces

The electric reduction furnaces which are extensively employed for the manufacture of ferro-alloys, are also arc furnaces of special design as shown in Fig. 8. The operation of this type of furnace in the production of ferro-alloys was recently reviewed by Sieveking[7], who gives a considerable amount of useful data. This data is summarised in Table I which is taken from his paper.

The raw materials used in the production of these alloys consist of steel scrap or turnings, iron ore, the alloy ore and a reducing agent, which is generally coke. In the production of ferro-silicon the raw materials usually consist of quartz, old silica bricks, anthracite coal and steel scrap or turnings. The raw materials are fed through shutes at the top of the furnace and the alloy is tapped off from a tap-hole at the base. The process is continuous, there being no interruption for charging or tapping.

5 Patent Rights, British Patent, No. 556048.

6 Bashforth, *Trans. Staffs I. & S. Inst.*, 1941-3.
7 Sieveking, *Jn. Inst. Elect. Eng.*, Vol. XC, Feb., 1943.



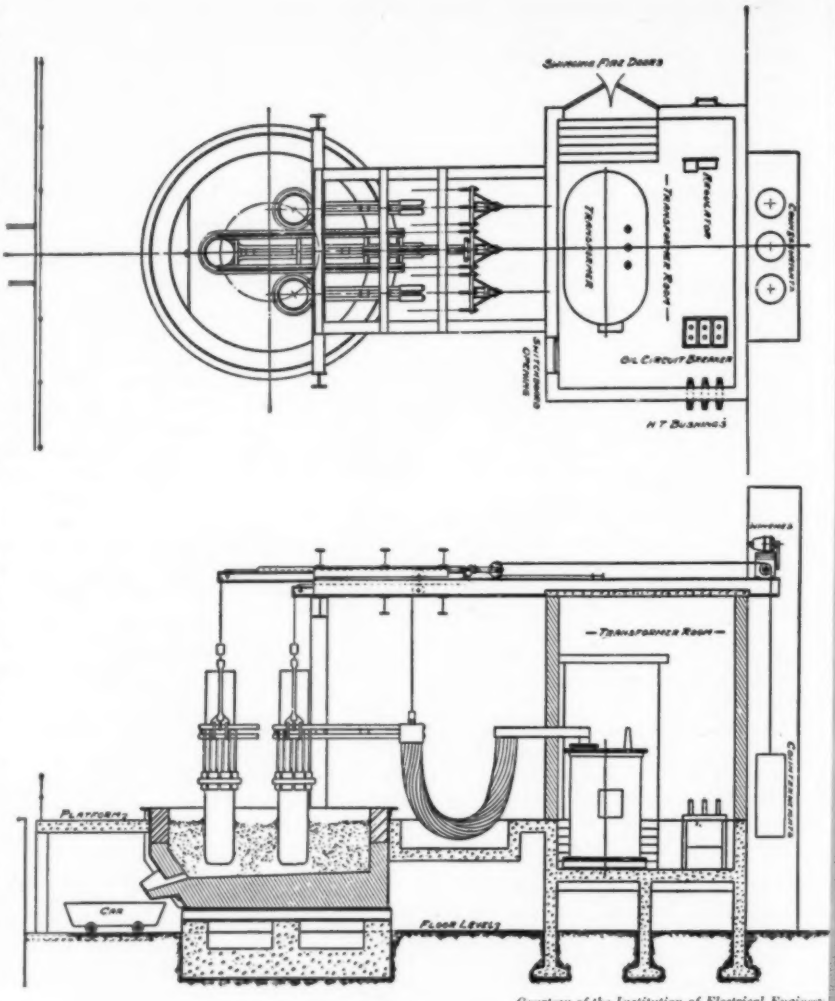
Courtesy of the Staffordshire Iron and Steel Institute.

Fig. 7.—Effect of staggered operation on load factor.

In the manufacture of these alloys a constant voltage ranging from 60 to 250 volts is employed. There are no violent fluctuations in power consumption, so that a good load factor is maintained. Transformers are provided to give the required voltage but reactors are not required. Units with ratings up to 30,000 kVA. are in service, whilst the maximum current rating at present is 100,000 amp. per phase for a 3-phase unit and 300,000 amp. for a single phase unit.

The type of electrode employed varies with the size of the furnace. On medium capacity furnaces the electrodes are of amorphous carbon and are about thirty inches in diameter. On larger furnaces Söderberg electrodes are used. These electrodes consist of ground carbon and a binder, which is usually pitch, rammed into a tube made from thin steel sheets. The steel melts and forms part of the charge. These electrodes are frequently forty-five inches in diameter and have a current density of 25 amp./sq. in., or 40,000 amp. per electrode.

In view of the large tonnage of these alloys imported it would appear that their production in this country merits serious consideration. The necessary raw materials, if not available, are at least fairly readily accessible. The high power consumption, however, demands very cheap current if their production is to be economic.



Courtesy of the Institution of Electrical Engineers

Fig. 8.—Electric reduction furnace.

TABLE I—MANUFACTURE OF PRINCIPAL FERRO ALLOYS (Sievking[7])

Type	Analysis	Power Consumption kWh/ton.
Ferro Chrome	Cr 70%, C 0·06%, Fe 30% .. .. Cr 70%, C 2·00%, Fe 28% .. .. Cr 70%, C 6·00%, Fe 24%	9,000-18,000 10,000 7,000
Ferro Manganese	Mn 80%, C 7·0%, Si 1·0%, Fe 12% Mn 80%, C 0·75%, Si 7·0%, Fe 12%	3,500 7,000
Ferro Manganese Silicon	Mn 55%, Si 24%, C 0·6%, Fe 20%	3,000
Ferro Molybdenum	Mo 60%, C 1·5%, Fe 38·5%	10,000
Ferro Silicon	Si 45%, Fe 55% .. .. Si 70/75%	5,000 12,000
Ferro Tungsten	W 80%, C 2·0%, Fe 18%	8,500
Ferro Titanium	Ti 25%, C 0·1%, Fe 75%	7,500
Ferro Vanadium	Va 40% (C+Si) 11%, Fe 49% ..	7,500
Silico-Manganese	Mn 68%, Si 20%, Fe 12%	10,000

To be concluded in the next issue.

Armourers and Brasiers Research Fellowship in Metallurgy

A joint Committee of the Royal Society and the Armourers and Brasiers' Company have appointed R. W. K. Honeycombe, M.Sc., of the Cavendish Laboratory, Cambridge, to the Armourers and Brasiers' Research Fellowship for two years from October 1, 1949.

Mr. Honeycombe, who graduated B.Sc., Melbourne in 1941 and M.Sc. in 1943, will work on the inhomogeneity of plastic deformation in metals, and the influence of these inhomogeneities on recrystallisation and recovery.

The Herbert Akroyd Stuart Award, value £50, offered biennially by the Institute of Marine Engineers under the will of the late Herbert Akroyd Stuart for the best paper on the development of the heavy oil engine, has been awarded to Mr. John Lamb, O.B.E., M.I.Mar.E., for his paper entitled "Burning of Boiler Fuel in Diesel Engines" read on December 9, 1947, and published in the Institute's Transactions of February, 1948.

Design in Powder Metallurgy

By H. W. Greenwood

Powder Metallurgy, Ltd., London

Some engineers regard powder metallurgy products with disfavour, but their numbers will diminish as they realise the fundamental rules governing the design of parts to be produced and the particular advantages powder metallurgy technique offers. In this article is emphasised the importance of design.

WE usually think of design in powder metallurgy, if we think of it at all, as being concerned largely with the limitations imposed by the materials and the method. A somewhat closer examination of the subject, especially bearing in mind development and progress of the past few years, indicates that there are several aspects of the question, and that the influence of powder metallurgy on design has a number of facets worthy of examination and study. In addition there may be another aspect, namely the influence of design on powder metallurgy, which in the not distant future may be a factor of some importance.

Up to the present we are mainly familiar with the effect on design, first of the materials used and their specific properties, and then of the tools and processes employed to produce the finished compact. Here we have to consider specially the lack of plastic flow under economical pressure, the friction of metal powders on the sides of the die and the faces of the punches, and the mechanical limitations of dies and tools. In these matters the rules of design have developed as the result of practical experience. We take it for granted that in the finished part we must have reasonably equal distribution of density throughout all parts of the compact if it is to offer reasonable physical properties evenly distributed. That accounts for the general rules covering relations between length and breadth or diameter, thickness of walls in hollow cylindrical objects in relation to outside diameter, limits of variation in cross section. These are all limits that practice has dictated. There are many other comparatively simple relations such as those dealing with radial projections, re-entrant angles, sharp edges and other items in which the actual design is determined after consideration of both material and tools as well as the desired final product. We speak of these as simple relationships, but it is because the necessity for them is so often ignored that powder metallurgy has come to be looked upon as a disappointing branch of metallurgy and is held in disfavour by many engineers. There are two outstanding reasons for this disappointment and disfavour, they are failure to appreciate the properties of metal powders and the processes used to mould and sinter them, or lack of consideration for the economics of the processes and inability to judge between rival methods.

It will be realised that these considerations apply mainly in those cases where powder metallurgy is ranged in competition with other processes capable of producing components of the same function and shape as those produced by powder metallurgy. They do not normally arise over components that can only be produced by powder metallurgy. A very common experience of the powder metallurgist is to be confronted with a component which should preferably be produced by some other technique such as diecasting, cutting from an extruded form, or by simple stamping. It is a safe forecast that such experiences will diminish as engineers and others realise the fundamental rules governing the design of parts to be produced by powder metallurgy and the particular advantages the technique offers. Another common request is to undertake the production of a part which, because of poor design, is not suitable for powder metallurgy, but can be re-designed so that not only will the part be perfectly satisfactory, but it will offer greater strength, better balance and symmetry and better performance. Such a well designed part can usually be produced with notable economy, and such examples have a valuable and an important part to play in emphasising the effect of good design.

Very many small parts used in industry to-day have had little care lavished upon them. Because they have no heavy duty to perform and can usually be produced quite cheaply they have not been designed in any real sense of the word. As demand has increased they have been called for by the hundred thousand, even the million, while at the same time better performance has been asked of them and heavier duties imposed. Powder Metallurgy has been asked to help in their production, but has not enjoyed the success anticipated because sufficient attention has not been given to design. There have been cases in the past where owing to improper design there has been unnecessary wear on dies and punches, warping or undue shrinkage of compacts during sintering, and even damage and loss in the green compact stage. Such conditions can arise only when there is general ignorance as to the requirements of powder metallurgy in the matter of design and should certainly not occur to-day.

The greater care exercised in design applies also to the material to be used in producing parts. In the early days of powder metallurgy most of the components were such as could only be produced by that method such as porous bearings, electrical contact material and later hard-metal tools. To-day there is an insistent demand for dense materials, and hardness and wear-resisting qualities are asked for. That tendency will grow and will eventually lead to powder metallurgy providing a very big range of components having properties not obtainable by any other method, but of a very different type and quality as compared to to-day's productions. Such conditions rule out carelessness in design and demand first scrupulous attention to design as it applies to form. The rules governing relations between axial length and breadth or diameter, between wall thickness and diameter in hollow cylindrical components, the avoidance of large or abrupt changes in cross-sectional area, all these are fundamental and should be known by all, but there are in addition very many matters of first importance that are not instantly obvious because they are peculiar to powder metallurgy.

It may be useful to indicate what are called the three fundamental limitations which have already been mentioned and explain how they affect the products. The first is the lack of plastic flow in metal powders when under pressure. It is easily realised that in a die in which powder is under pressure there is practically no tendency for the powder to flow from a region of high compression to a region of lower compression. Therefore, density will be highest where the punch has contacted the powder. If, as is usual, a press has a two-way action and pressure is applied from above and below, the distribution of pressure will be such that at the close of the pressing operation the compact will have a higher density at each end than in the centre. If the part being formed is one in which there are appreciable dimensional variations in thickness parallel to the direction of pressure, then it will not be possible to maintain uniform density throughout the part if only a single punch is used. This is very elementary, but it is also very often overlooked by those who approach the powder metallurgist and ask for parts to be produced which offer all sorts of problems due to failure to appreciate just these elementary matters.

The second fundamental limitation is the friction engendered between the metal powder and the die walls and punch or punches. This can be very appreciable and emphasises the importance of reasonable lubrication of die walls. This second limitation supplements the first so far as affecting the distribution of density in the pressed compact is concerned ; in addition there is the wear and tear of die, dependent partly on the nature of the metal powder being pressed, and partly on the pressure being applied. Here adequate lubrication of die walls can be an important factor on the economic side, but good design of the part will be the largest factor in ensuring economic production because any failure in design inevitably leads to loss and wastage not only at the stage of handling the green compact, but even more during sintering where lack of balance or symmetry in the design is a fruitful source of warping and so of loss.

The third fundamental limitation is that imposed by tools and dies. It has to do mainly with the shape of articles and calls for the elimination of re-entrant angles, grooves round the periphery of cylindrical shapes, and for special consideration of all designs where there are narrow die recesses which are always difficult to fill, or where there are narrow splines or complex radial configurations which increase the area in contact with the sides of the die. In this category fall those cases where in design a small " land " is required wherever a tapered part begins and the tool stops. If the " land " is not provided there is a feather edge in the tool which soon causes trouble. A similar precaution is called for at corners or edges which could cause a burr. Here they should be chamfered. It should be obvious that at the present stage of powder metallurgy designs cannot admit of holes not parallel to the pressing axis.

It might appear from this catalogue that the limitations far outweighed the advantages of powder metallurgy. A little thought will suffice to show that a similar list of limitations could be drawn up for other production processes. The fact that it is not necessary to do so is due to the almost traditional " know how " which the older processes possess. The powder metallurgical " know how " is only accumulating, but it will not be very long before it is much more widely disseminated than at present. Meanwhile the influence of progress in powder metallurgy upon the design of parts is perceptible and is growing. Already the technique is producing details equal to, if not better, than those which casting can offer, and we are already looking forward to more than equalling parts produced by machining from cast or wrought material. That points quite definitely to the time when the products of powder metallurgy will no longer compete with others because products of equal properties will not be available by methods other than those of powder metallurgy. Those who doubt this can consider the remarkable progress made by powder metallurgy in the past few years, especially in the production of materials having excellent physical properties, and offering entirely new possibilities in the direction of heat-treatment. Consider the part cemented steels can play in this field and the influence of such possibilities in the field of design. These cemented steels are all capable of being subjected to conventional heat-treatment, they can be strengthened by precipitation hardening and when so treated are easily machinable. They have admirable self-brazing characteristics which offer very notable advantages from the assembly point of view, especially the building up of complicated structures from separately produced, carefully designed parts.

It is with possibilities of this kind in mind that we can speak of the influence of powder metallurgy on design in a wider and fuller sense than that of the imposition of limitations, an influence, in fact, that may well have repercussions over the whole field of engineering.

Baden-Powell Memorial Prize

THE Baden-Powell Memorial Prize, awarded to the best candidate in the Associate Fellowship Examinations of the Royal Aeronautical Society in the May, 1949, examinations, has been awarded to Mr. P. J. Wingham, Student Member.

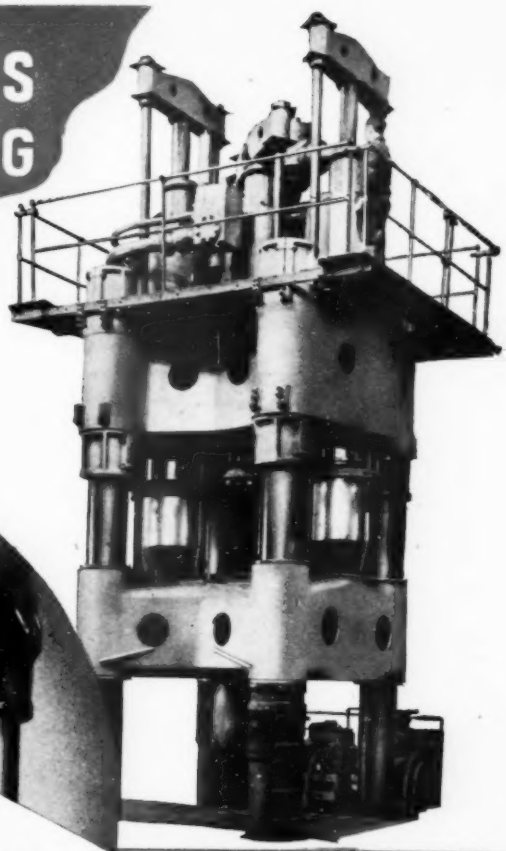
Electrolytic Polishing

A NEW British company has been formed for the purpose of licensing, in the British Isles and in the British Commonwealth, electrolytic processes for polishing, super-finishing and allied treatments for metallic surfaces. Modern Electrolytic Patents and Processes, Ltd., whose Chairman is Col. W. C. Devereux, C.B.E., F.R.Ae.S., and Managing Director, Dr. H. E. Z. Gordon, Ph.D., D.I.C., Chem. E., has its Technical Offices at 46, Bryanston Street, W.1., and its Registered Office at 11, Ironmonger Lane, E.C.2.

The Company holds the rights for all electrolytic polishing processes patented by the Batelle Memorial Institute, Ohio, U.S.A., and by the Societé Jacquet-Hispano Suiza, Paris; and Dr. P. Jacquet, a pioneer in the field, is acting in an advisory capacity to the Company's Technical Staff.

The process is at present used for three main types of applications :—(1) As a method of finishing metallic surfaces, including the preparation of metals for plating ; (2) As a method of inspection for a variety of engineering components made from special alloys ; and (3) As an " electromachining " operation, i.e., a method of uniformly removing a certain amount of metal under carefully controlled conditions. Among the metals and alloys which can be treated successfully on a commercial scale are stainless steels ; copper and brass ; aluminium and some of its alloys ; and certain carbon steels and special alloys.

SCORED MAIN RAMS OF 3000-TON FORGING PRESS



We are indebted to Messrs. High Duty Alloys, Ltd., Forging Division, Redditch, for permission to reproduce the accompanying photographs of a press and the rams on which work was done for them.

RESTORED By "FESCOL"-ising in Nickel

Inset illustration shows the three main Rams of a 3,000-ton Schloemann Forging Press used for forging light alloy. The rams are 28¾ ins. diameter by 8 ft. 6 ins. long and were worn and scored in service. The method of treatment adopted was to "FESCOL"-ise the rams in nickel and to build up bushes and neck rings in copper to suit the new dimensions of the rams.

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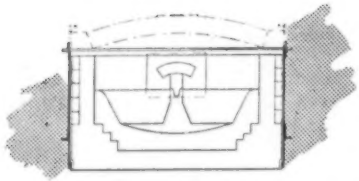
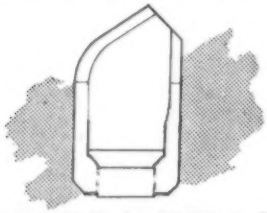
G·R '341'

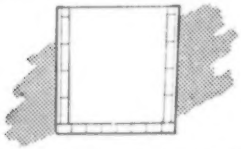
DOLOMITE BRICK



ELECTRIC FURNACES G.R. '341' dolomite bricks are used extensively in walls and bottoms of basic electric arc furnaces. Proved the most economic basic brick available. Complete absence of chromic oxide makes '341' most suited for production of chromium-free alloys. Any size furnace can be lined from standard stock sizes.



BASIC BESSEMER CONVERTERS G.R. '341' bricks, dense and burnt to vitrification at high temperatures are superior to rammed tarred dolomite or 'green' tarred blocks in the lower wall positions. In addition to giving longer and uniform life to the converter the efficiency of the process is greatly improved. Highly resistant to chemical erosion and mechanical attrition.



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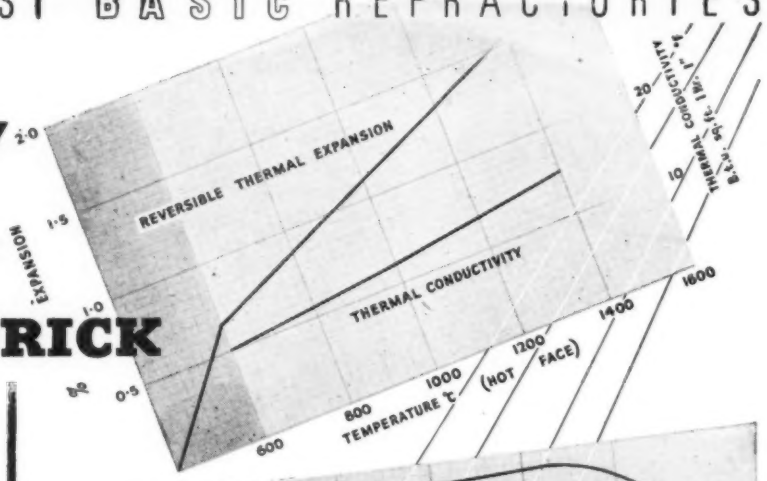

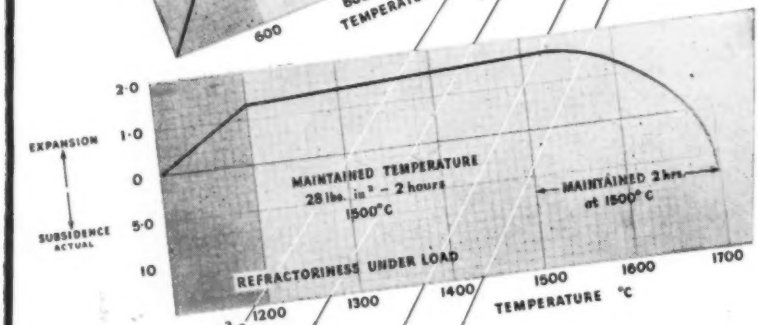

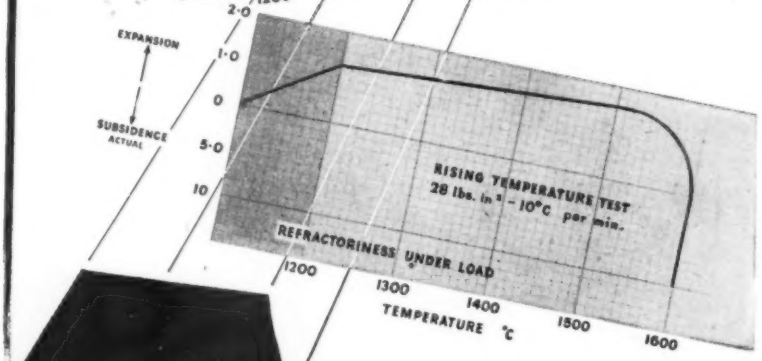

The widespread and successful use of the G.R. '341' dolomite brick in Basic Electric Furnaces, Bessemer Converters and Desulphurising Ladles is one of the major achievements in refractories. G.R. '341', the result of many years research and experimentation, is manufactured entirely from British Dolomite and is treated to ensure resistance to atmospheric moisture. Like all G.R. Basic Bricks, '341' is made in one of the most modern plants, embodying all the features of improved brickmaking technique and possessing valuable characteristics developed by years of experience. Full information and advice on the selection and application of refractories will be given on request.

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Useful Molybdenum Steels

Data Sheet 3

SPECIFICATION Nos. TENSILE STRENGTHS AND IZOD VALUES FOR CASE-HARDENING AND NITRIDING STEELS

En. No.	Tensile Strength (Min) Tons/Sq. in.	Izod Impact (Min) Ft. lb.	Ruling Section Inches
FOR CARBURISING			
34	45	40	Test Bar 1⅛″ dia.
35	55	25	do. do.
325	55	35	do. do.
39B	85	25	Test Piece Size
320	85	25	do. do. do.
FOR NITRIDING			
40A	45	40	6″
40A	50	40	6″
40B	55	40	6″
40B	60	35	4″
40C	Higher Tensile*		
41	35	45	Izod Values applicable up to 2½″
41	45	40	
41	55	35	

*Mechanical properties as agreed between purchaser and manufacturer.

CHOOSING A CASE-HARDENING STEEL

The level of core strength for the part concerned must be decided.

Case hardness and case depth must be known. Freedom from distortion and good machinability are also vital factors.

Molybdenum-containing steels are extensively used when these things count.

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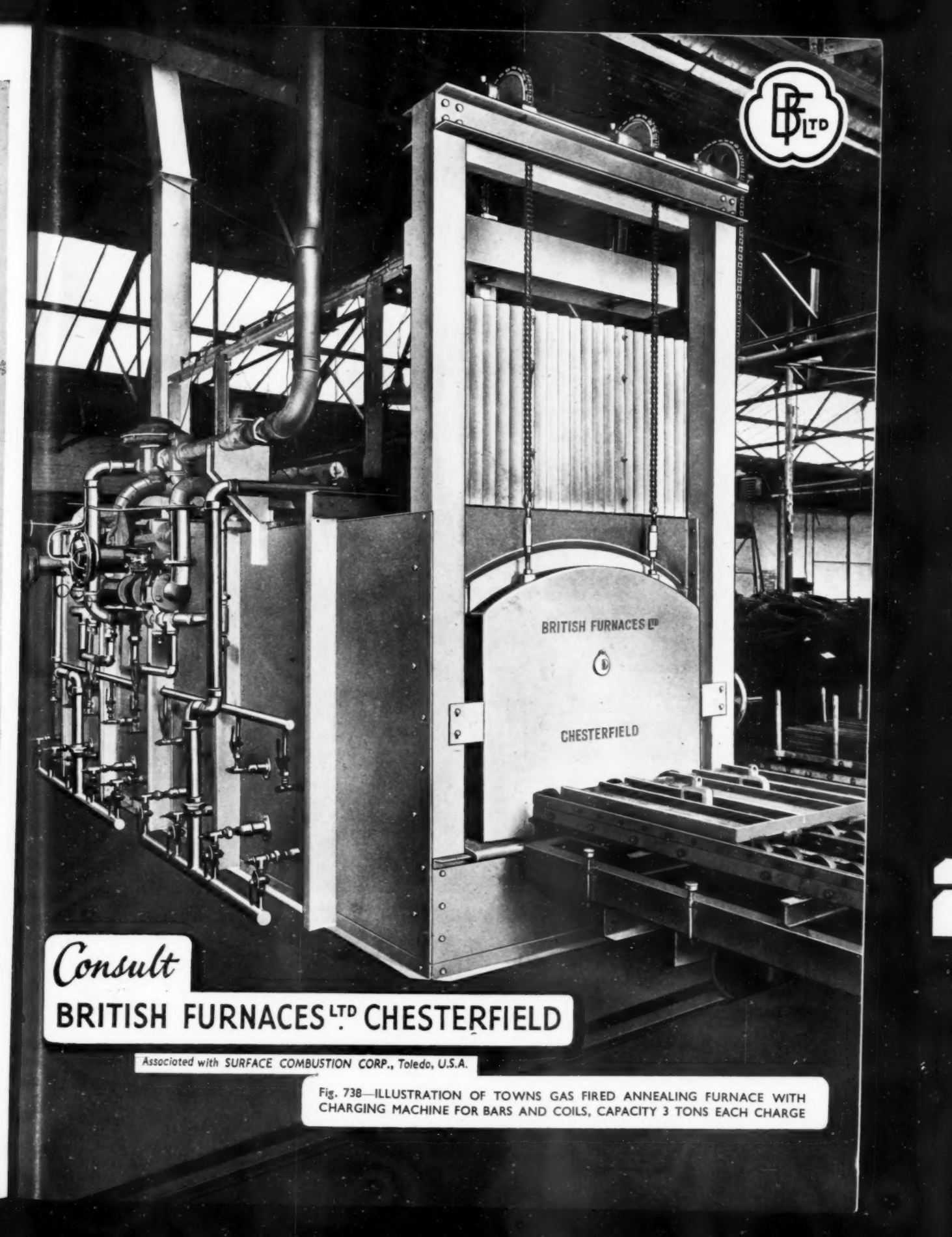

Consult

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Fig. 738—ILLUSTRATION OF TOWNS GAS FIRED ANNEALING FURNACE WITH CHARGING MACHINE FOR BARS AND COILS, CAPACITY 3 TONS EACH CHARGE

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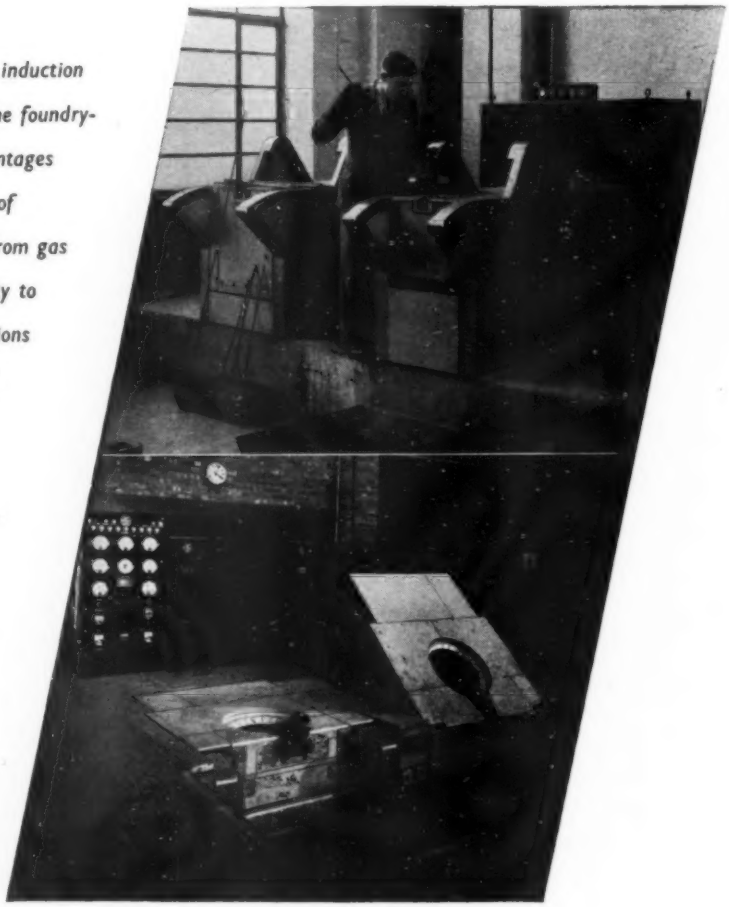

Two BIRLEC-Northrup induction melting installations are illustrated : upper picture — 100 lb. and 200 lb. furnaces : lower picture — two 1 ton furnaces.

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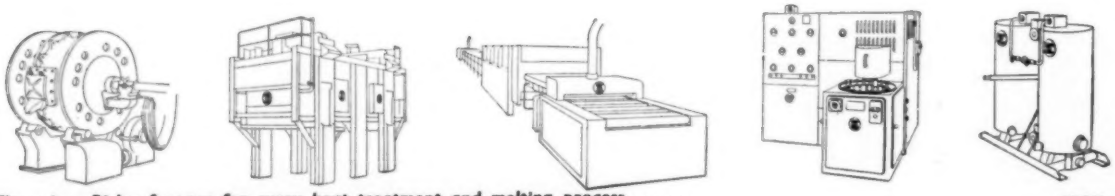

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Iron CASTINGS

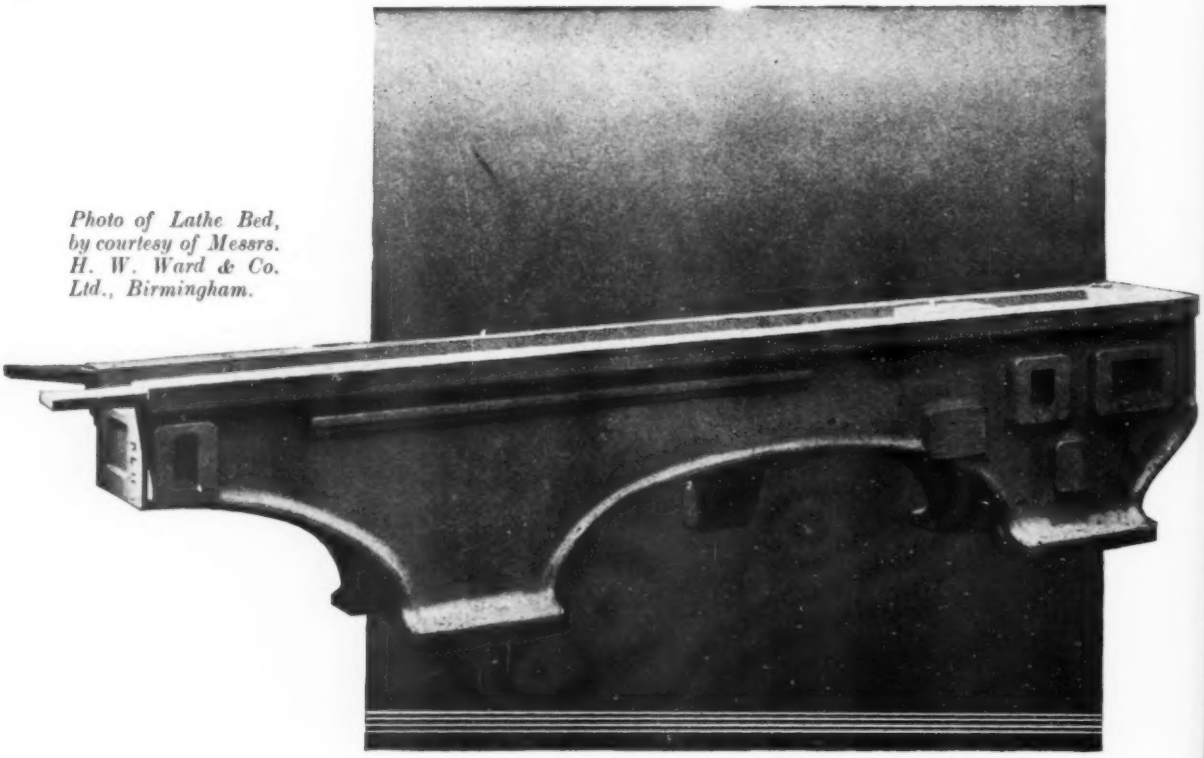

Photo of Lathe Bed, by courtesy of Messrs. H. W. Ward & Co. Ltd., Birmingham.

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Co-operative Research Activities

Reports of Research and Development by British Associations

Progress in industry can only be achieved by making full use of scientific developments. In normal times the application in industry of increased knowledge resulting from research is slow, but, in the present dangerous economic and financial condition of this country, the need for speed was never more necessary. Brief reports are given from a number of research associations summarising work done and in progress that is contributing to the nation's need for better and cheaper production in metallurgical and kindred fields.

ALTHOUGH the gulf that formerly existed between scientific knowledge and its application in industry is being narrowed there is need for greater speed, especially in view of the dangerous economic and financial position with which Britain is confronted. A nation does not differ from an individual insofar as it cannot spend more than it earns, it can only escape disaster by realising in time that all means must be taken to increase its earnings. Since Britain must buy from overseas she must at least balance her expenditure by exports and the goods exported must be competitive in quality and cost. To make goods better and cheaper involves constant research and development and the rapid application of the results obtained. Research leads to the development of new processes or improvements in existing processes, new machines, new materials and new applications of these materials and, under modern conditions, an industry can thrive and develop only by continually examining its production facilities and materials with a view to effecting improvements; it must be keenly alive to progress in its particular field, for unless it can maintain or preferably increase its market, it soon ceases to be profitable.

While many of the larger firms have set up their own laboratories and carry out investigations with a view to improved and cheaper production, where new products and more advanced production techniques can be developed and many of the day to day production problems can be carefully examined and finally solved, smaller firms are frequently at a disadvantage. To assist these latter firms, co-operative research organisations have been functioning for many years, some of which are private research laboratories, while others, partially supported by the Government, have been specially instituted to carry out research and development work in particular fields of activity. It is with some of the latter that the following reports are concerned and they are presented so that readers may be kept informed on the work done, in progress, and contemplated by these associations.

The British Iron and Steel Research Association

A selection of a few of the more interesting and immediately important projects this Association has in hand are summarised. Much work referred to has been undertaken at the works or laboratories of individual firms and is therefore co-operative in the fullest sense, since the results become available to industry as a whole. Although the work of the Physics and Chemistry Departments has been omitted from this report a very wide range of fundamental work has been undertaken.

THE fundamental nature of the iron and steel industry in relation to national economy opens an enormously wide field to the British Iron and Steel Research Association. At any one time the Association is engaged upon from 300 to 400 research projects, varying from the most detached fundamental studies to the most arduous of application trials. All are directed urgently to the same end; the efficiency and productivity of the iron and steel industry of Great Britain. And since the Association's task reaches from the assembly and preparation of raw materials, throughout the basic processes of manufacture and the shaping and forming of the finished products, to the properties and quality of the finished products themselves its activities are concerned with the productivity of a great number of user industries as well.

A recent publication illustrates some work of value to users, and also embodies the useful results of a great deal of detailed co-operative research. Such work is undertaken at the works or laboratories of many individual firms and is therefore co-operative in the fullest sense of the word.

"The Atlas of Isothermal Transformation" was published in June, 1949, and is likely to be of great value to every industry concerned with heat treatment of steel. "S-curves" as these transformation diagrams are generally known, show what happens to the structure of a particular steel when it is held at a certain temperature after rapid cooling from a given "austenising" temperature above the critical temperature—the latter usually falling within the range 750° C. to 850° C.

Figs. 1(a) and 1(b) show two typical sets of curves in the Atlas. Fig. 1(a) relates to nickel steel (EN 21), and Fig. 1(b) to 3% nickel-chromium steel (EN 23).

Transformation characteristics vary, of course, according to the composition of the steel, so separate curves have to be plotted for each specification. In the "Atlas" curves have been plotted for 24 of the British Standards Institution's EN series detailed in BS 970.

The main purpose of S-curves is not to provide data for the design of heat treatment schedules, but a basis for appreciating the behaviour of steels when quenched in sections which do not harden completely.

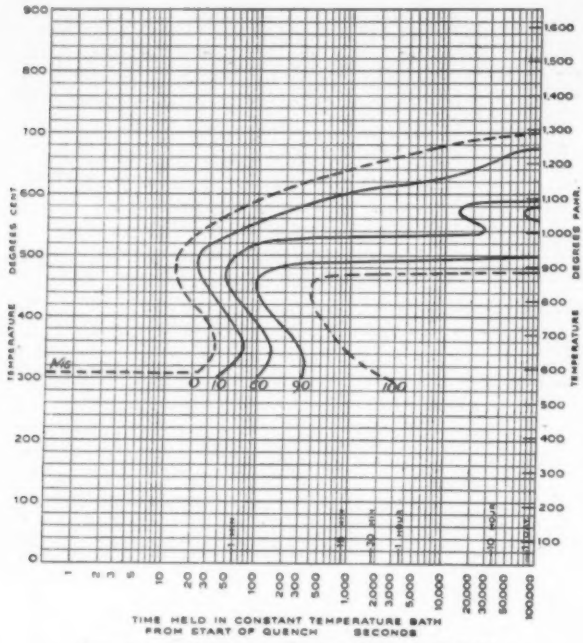


Fig. 1(a).—Relating to nickel steel—EN 21.

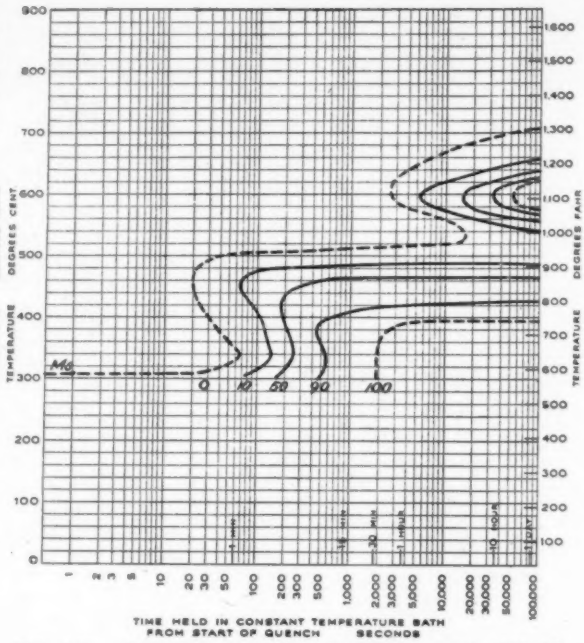


Fig. 1(b).—Relating to nickel-chromium steel—EN 23.

Two typical sets of curves from "The Atlas of Isothermal Transformation"

Another publication of major interest to many of those concerned with the use of steel is "The Corrosion of Iron and Steel by Industrial Waters and its Prevention." The importance of corrosion needs no emphasis. This book is divided into four sections, (i) Introductory, (ii) The Causes, (iii) The Occurrence, (iv) The Prevention of Corrosion in industrial plant, and being copiously illustrated and exceptionally well furnished with references to papers on the subject it should prove invaluable.

These are two examples of the Association's concern with the properties of ferrous metals. Illustrating another aspect is work that has been done on optical methods of examining metals. On May 9th and 10th, 1949, a conference to discuss this subject was held at Ashorne Hill, Leamington Spa, under the general chairmanship of Mr. E. W. Colbeck, of Messrs. Hadfields, Ltd. The purpose of the Conference was to encourage the application in metallurgical industry and research of known optical techniques. This objective itself is of interest. It is often found that a considerable economy of effort is achieved by the application or adaptation of methods already in use in other fields of science, but insufficiently known to those concerned with metallurgical investigations. At this Conference, therefore, practical metallurgical application of three techniques already in existence, two of them commercially available, was the main topic of discussion. Papers, practical demonstrations and essential theoretical treatments were presented and discussed, the three techniques being :—

(i) phase contrast microscopy,
(ii) multiple beam interferometry,
(iii) the reflecting microscope.

The diverse interest aroused by such a conference is indicated by the fact that no less than 160 delegates attended for the two days of very vigorous discussion and of these about 100 came from industry, 24 from 9 Universities and the remainder from Research Associations and similar bodies.

Mechanical Working

The methods by which the Steel Industry's products are shaped afford an interesting example of how fundamental and applied researches are closely linked.

Reference was made in last year's report to the fact that plans were in hand for the establishment of a research station for the study of metal working problems in Sheffield. In the meantime a temporary laboratory building has been erected which has made it possible to broaden the Association's work in this field to include, in addition to rolling, wire drawing and forging. Laboratories for the development of instruments and for metallurgical investigations connected with metal working have also been provided. The fundamental side of the work is catered for by a newly established "solid mechanics" section, which is carrying out investigations into the mathematical theory of metal flow ; other work on plasticity is being carried out at the Cavendish Laboratory, Cambridge, on behalf of B.I.S.R.A.

The deep drawing and pressing of sheet is of interest alike to the steel industry, the non-ferrous metal industry and the motor industry. Research is being jointly sponsored by B.I.S.R.A., the Motor Industry Research Association and the Non-Ferrous Metals Research Association, in the University of Sheffield under Professor Swift.

On the more practical side, the cold rolling of steel strip under tension has been one of the principal items of study in the Rolling Section programme, and it is hoped early in the next year to begin work on hot rolling by means of field trials, aided by special instruments developed in the Rolling Mill Laboratory. Some of these instruments were exhibited at the Physical

Society's exhibition last April and excited considerable comment.

Laboratory work on wire drawing is in its early stages, the main part of the work having hitherto been carried out in the form of a major works study on a new backpull wire drawing machine. The advantages and disadvantages of backpull wire drawing have been much discussed in recent years, and the work which has been done by B.I.S.R.A. during the last 12 months has thrown considerable light on the practical value of this method of drawing and has led to the prospect of considerable advances in the drawing of high carbon steels.

Work at the Association's South Wales laboratories is mainly concerned with the measurement of surface finish of rolls and rolled strip, methods of coating, such as galvanising and tinning, and various forms of surface treatment such as acid pickling, and gas pickling. Perhaps the most interesting development in the application of surface finish measurement to the steel industry is the increasing use that is being made of this technique to control the surface finish of rolls so that they may be ground and maintained to a carefully specified finish.

Photo by courtesy of Stewarts & Lloyds, Ltd.

Fig. 3.—Gas velocity experiments on a blast furnace at Corby. Gas is being drawn off from the "bottles" at the furnace top, where a series of samples have been collected at one second intervals after the projection of radon through one tuyere. The gas drawn off will be tested for radioactivity at the Associations Physics Laboratories.

Manufacture of Steel

Turning from the shaping of steel to its manufacture we consider first the problems concerned with the casting of steel in the steel foundry. The Steel Castings Division of B.I.S.R.A., like the five other divisions of the Association, acts in an almost autonomous capacity as a sort of junior research association for that section of the industry of which it is a part. An interesting example of this division's work is that concerned with investigation into refractory wear in sideblown converters.

The effects of different refractory materials and operational factors upon the life of cupola and converter refractories were considered at an Ashorne Hill conference in May, 1949. General opinion seemed to be that the effect of operational factors outweighed difficulties in the refractories themselves.

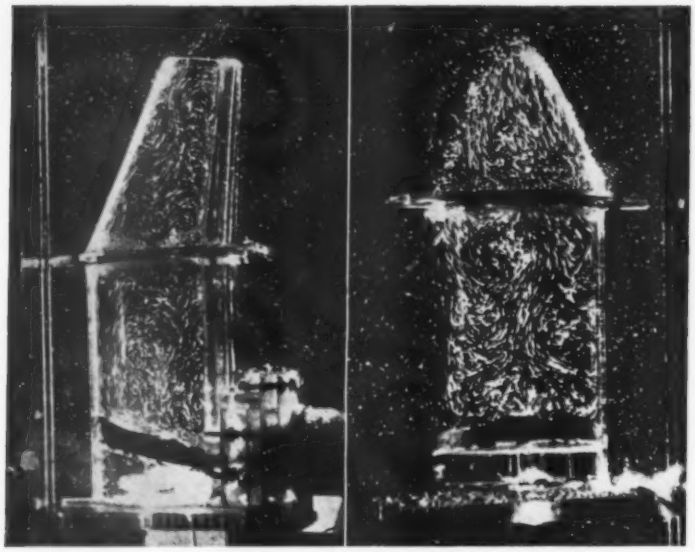
A previous consideration of this subject had already led to the institution of aerodynamical studies in a model converter at the Physics laboratories of the Association (see Fig. 2.). These studies, which are still continuing, appear to indicate that the present converter shape is conducive to eddying, and regions of greatest wear may be associated with the gas flow pattern. It has been shown that above the tuyeres hot blast may travel in the opposite direction to the incoming blast so that it impinges upon the refractories. To investigate the accuracy of these deductions from flow patterns in small scale models a water-cooled periscope is under construction which it is hoped will enable observations to be made of the motion of metal surface during actual blowing in a side-blown converter. Meanwhile research continues on the designs which should give reduced refractory wear.

In this connection fundamental research has begun on the impact of gas jets on liquids in order to assist in the understanding of the operation of the surface-blown converters.

Some of the most interesting work of the Steelmaking Division itself concerns the use of basic roofs in basic open hearth furnaces. Normally the roofs of all open hearth furnaces (for both acid and basic steelmaking processes) are built of silica bricks because they maintain their strength almost up to their melting point, whereas most basic bricks lose strength at high temperatures and "spall" if temperatures fluctuate widely. On the other hand, basic bricks have a higher melting point, and if the disadvantage of their comparative mechanical weakness could be overcome, furnaces could be worked at higher temperatures. The extraction of magnesia from sea water in this country and the manufacture of magnesite has helped the refractories industry to make chrome magnesite bricks with which basic roofs can be constructed for trial purposes.

The fundamental work leading up to these "all basic" furnaces was carried out by the British Ceramic Research Association at the request of B.I.S.R.A. The trials now running cover three distinct types of roof design, ranging from fully suspended to a self-supporting arch. Accurate comparisons of different basic refractories are being made by means of "split" roofs and the inclusion of test panels. In addition, the largest trial furnaces (160 tons) will have the first roof in the country constructed entirely of unfired, chemically bonded, chrome magnesite bricks. The furnaces are highly instrumented and as much detailed data as possible is being collected.

Three all-basic furnaces built of bricks of British manufacture have now been in operation long enough to show that the higher operating temperature can lead to an increased output of about 15 to 20%. The refractory



Section through tuyeres Section at right angles to tuyeres

Fig. 2.—Photographs showing patterns of flow in converter model.

wear on these furnaces appears to be satisfactory but the trials will have to last at least another two years before the economics can be properly assessed. Trials at two other works at least are planned to start during this autumn.

Other furnace trials concern new and simpler designs for the ports of open hearth furnaces, originally tried on the Association's experimental open hearth furnace at the works of Shelton Iron, Steel and Coal Company. Work along these lines is by no means completed but it is already thought that one of the developments, the development of a single air uptake in open hearth furnaces, represents valuable progress in open hearth furnace design.

Another extensive and important field of operation for the steelmaking division conerns the use of oxygen in open hearth steelmaking and work trials are in progress in all steelmaking districts. Trials of the use of oxygen both in electric steelmaking furnaces and Bessemer converters are also in progress.

Ironmaking

Blast-furnace research, ranging from the unprepared raw material to the hot metal leaving the furnace, presents many special problems in a wide field.

The very size and long life of the blast furnace are factors which make full-scale experimental work difficult and lengthy. The Ironmaking Division of B.I.S.R.A., therefore, has teams of 'field trials investigators' who are evolving techniques for exploring the working of the furnace without interrupting normal production. By adding in this way to knowledge of the process, they are paving the way to development of methods for further control and economy.

A water-cooled gas sampling probe, for example, was built into a 20 ft. hearth blast-furnace at a member firm's works, prior to the blowing-in. It projected to the centre of the furnace, about 11 ft. below the stockline, and through it samples of gas at intervals between the centre and the wall were withdrawn for analysis. The carbon dioxide content was found to very considerably with time at all sampling positions, but in general it was found to be greater at the centre than at the walls for this particular furnace —a result which was unexpected on the assumption of a "V" stockline contour, and which shows that some factors in the blast furnace operation are not yet understood.

The anomalous results obtained emphasised the need for more complete knowledge of conditions at the stockline, and consequently a direct mechanical technique, using a weighted Bowden wire working through a moveable tube, has been evolved, and has given a good picture of the shape and rate of descent of the stockline in a number of operating furnaces. This technique is in addition to longer-term research devoted to obtaining a continuous record of the stockline contour by reflection of ultrasonic pulses.

Similarly, a knowledge of the actual and relative velocities of the gas at varying distances from the centre is required. Preliminary experiments have established the success of a technique using a radioactive tracer (see Fig. 3.). Radon is projected into one tuyere by means of a detonated explosive charge; at the same time sampling of gas from the stockline begins. The transit time of the gas is deduced, when the samples are tested for radioactivity, and it has been found possible to estimate the differences in transit time between the centre and the walls. Gas transit times so far observed have been considerably longer than were expected. The results are of particular interest in connection with the high-top-pressure method of operation evolved in the U.S.A., the net effect of which is to diminish the gas velocity and so increase the time available for the reducing gases to react with the iron ore of the burden.

These items, and others in the project list of the field trials teams, applied to various furnaces in the country, are enabling a more complete picture of the blast-furnace process to be gradually built up.

Raw Materials

An outstanding example of co-operative research work in conjunction with raw materials problems is the investigation on production of sinter from wet Northamptonshire ore fines.

With the continued assistance of a member firm, this work has been carried out on the full scale over the last 3 years. The specific questions concerning sinter quality formulated at the beginning of the investigation have now been answered by a series of specially designed trials. Questions concerning output remain outstanding.

The work has involved the design and installation of experimental engineering equipment, including part of its development for full-scale production. Continued observations of normal production, and experiments under more controlled conditions have established that variations in amount and quality of the raw materials have an over-riding effect on sinter quality. A series of trials dealing with other operating factors, such as

extremes of moisture content and variations in suction, support this conclusion.

Additional plant used for trials included a high-speed hammer-mill developed as an experimental tool for combined crushing and mixing of the sinter burdens. Initial difficulties due to wear on the hammer faces have been overcome by using tungsten carbide as a hard-tipping material.

A more recently initiated project of B.I.S.R.A's Ironmaking Division is its work on ore beneficiations directed towards the removal of slag-forming constituents from "lean" ores. This work has been stimulated by the gradual depletion of the more accessible ore beds in this country, and the need for methods of treatment which will render economic the utilisation of lower-grade deposits. The possible scope of this work is large, involving geological, mining and metallurgical considerations, and liaison work has been undertaken by the Operational Research Section in assessing the limits of permissible expenditure on beneficiation in the light of possible economies to the blast-furnace.

Engineering Research

There are many problems of organisation and operation which have to be considered in a wider context than is possible to any of the Divisions, naturally concerned chiefly with their own section of the industry. B.I.S.R.A's Plant Engineering Division has the task of carrying out such studies and a number have been made during the past 12 months. The handling of raw materials, the charging of open-hearth furnaces, the use of locomotives and the layout of integrated steelworks have all been subjects of such investigation.

The most recent one, and a typical project, is a survey of traffic in integrated steelworks. A number of firms in this country are experiencing difficulty in handling the growing rail traffic required to meet their increased production. A method suitable for analysing traffic problems in integrated works has been developed, and successfully tested at six works. It is based on studies of the use of railway tracks and time and motion studies of locomotives and wagons. Each type of works traffic has been considered separately and its importance evaluated.

Another valuable engineering project has been the hammering out of a specification for E.O.T. cranes for steelworks. Detailed discussions over 2½ years between major crane users in the industry and the crane makers in an *ad hoc* B.I.S.R.A. sub-committee have recently resulted in a specification designed to meet the special requirements of heavy-duty steelworks cranes and acceptable to the majority of the makers. The specification includes some novel features of "performance requirements" and is soon to be published as a Special Report by the I.S.I. Even before publication, however, its provisions are being put into effect, and at least one steels works has already placed an order for a crane to comply with the specification.

Associate Membership

It will be seen from the foregoing selections from a large programme that the Association's work covers a very wide field. During the period under review the Association's Council decided that the terms of membership were insufficiently elastic to admit the very great number of firms that are likely to be interested in all or part of the Association's work, though themselves not the makers or processers of iron or steel. A category of Associate Membership was therefore created for such firms, which are to have all the benefits of membership within such fields of activity as they may select. In the fields of coke and refractories, however, such close collaboration between B.I.S.R.A. and the respective research associations already exists that membership by firms in those industries, would serve little practical purpose.

Conclusion

The foregoing summary has been little more than a selection of a few of the more interesting and immediately important projects that B.I.S.R.A. has in hand. No mention has been made of the wide range of fundamental work undertaken by the two "Departments" of Physics and Chemistry. The former is particularly concerned with the joint researches on flame radiation which are being carried out by workers from this country, France, Holland and Sweden. The actual trials are being carried out in Holland at the experimental furnace at the Royal Dutch Steelworks. Part of the British contribution in the early stages is the design of gas temperature measuring equipment and hot background equipment for emissivity measurements. This has been the concern of the heat and thermodynamics section of B.I.S.R.A's Physics Department.

Conference on Foundry Steel Melting

SPONSORED by the Steel Castings Division of the British Iron and Steel Research Association, arrangements have been made to hold a conference on the above subject at Ashorne Hill, Leamington Spa, on September 22–23. Four sessions will be held—two on each of the two days—at which will be discussed the technical and economic aspects of the various processes.

Session I.—Cupola/Converter Process. "Its Scope and Limitations," by Mr. F. Cousans; "The Design of Converters," by Mr. A. G. Robietti; "Controlling Sulphur and Phosphorus Contents," by Mr. A. J. Langner; and "Application of Oxygen Enrichment," by Dr. W. C. Newell.

Session II.—Electric Arc Process. "Its Specialised Control for Foundry Use," by Mr. J. H. Pearce and Mr. W. Bramhall; "Refractories for Electric Furnaces," by Dr. J. R. Rait; "Electrical Characteristics, Output and Design of Arc Furnaces," by Mr. J. C. Howard; and "Steel Foundry Productivity," by Mr. F. A. Martin.

Session III.—Other Melting Processes. "Foreign Practice," by Mr. A. C. Brearley; "The Use of H. F. Process in Foundries," by Mr. C. McNair; and "The Use of Open-Hearth Furnaces in Foundries," by Mr. J. Mowat.

Session IV.—General Items. "The Fluidity of Different Steels," by Mr. J. E. Worthington; "The Cost of Melting in Foundries," by Mr. F. N. Lloyd; and "Specifications for Steel Castings," by Dr. E. Gregory.

Meeting of Junior Steel Plant Engineers

A MEETING of Junior Engineers is to be held at Ashorne Hill, Leamington Spa on October 19–20th next. The meeting is being arranged jointly by the Iron and Steel Engineers Group of the Iron and Steel Institute and the Plant Engineering Division of B.I.S.R.A. Mr. W. F. Cartwright, Chairman of the Iron and Steel Engineers Group, will be in the chair.

British Non-Ferrous Metals Research Association

By W. L. Hall, B.Sc., A.R.S.M.

Chief Liaison Officer, British Non-Ferrous Metals Research Association.

The immediate post-war period was one of rapidly expanding activity, while the period covered by this report has seen the consolidation of this Association's position and preparations for further expansion. In keeping with the country's economic condition emphasis is on the immediate application of scientific knowledge likely to increase industrial productivity and some of the more important developments are summarised, particular reference being made to new techniques.

IT is two years since the work of the British Non-Ferrous Metals Research Association was reviewed in this JOURNAL. The immediate post-war period was one of rapidly expanding activity, the last two years have seen the consolidation of the Research Association's position and preparations for further expansion.

New Laboratories

This year it has been possible to begin work on an extension of laboratory facilities, plans for which were prepared some time ago but not implemented owing to delays in obtaining the necessary building licence. The work in hand is essentially a reconstruction of a block of buildings destroyed by enemy action in 1940. The new building will house a metal working shop equipped with a 12in. × 12in. rolling mill, with sheet and section rolls, and a 500 ton hydraulic press and the intention is that the Association should be able to prepare experimental alloys in wrought form as required for its own research programme. In addition, the metal working shop will contain a small press suitable for powder metallurgy work, a small draw bench and suitable annealing equipment. The first floor will house general metallurgy, metallography, pyrometry and heat treatment laboratories for which only rather unsatisfactory accommodation is provided at present. Another floor will be devoted to administrative offices. Good progress is being made with the building work and the heavy metal working equipment is now being installed. At the same time, opportunity is being taken to extend the Association's foundry and to provide better facilities for research on galvanising and other molten metal coating processes.

Application of Research Results to Industry

The present economic condition of the country demands greater emphasis on the immediate application by industry of scientific knowledge likely to increase industrial productivity. Much attention has therefore, been given recently to improving the means whereby the Association can bring such knowledge to the notice of its members. The staff of the Information Department has been strengthened and increased use is being made of the technical library facilities provided. The total number of loans from the library to members and government departments, etc., in 1948, was just under 8,000, an increase of nearly 1,000 over the previous year. It has also been possible to prepare more translations of foreign technical papers for the use of members.

Considerable efforts have been made to increase the activities of the Liaison Department, which bears the main responsibility for assisting members to apply in practice the results of the Association's work. The number of major technical enquiries submitted to the Association in 1948 was 821, higher than in any previous year, and these enquiries continue to be received at an increasing rate. In the past year the service was used by 45% of the membership ; a measure of its usefulness, particularly to the firms having limited technical facilities. A large number of visits were paid to members to discuss technical problems and similar discussions were held with the many representatives of member companies who visited the Association's laboratories during the year.

Two important new measures were taken by the Association to improve its contact with the technical staff of members and to promote the early application of research results to industrial problems. Firstly, two residential conferences, covering the wrought copper alloy and the light alloy field respectively, have been held in the past 18 months. At these successful and well attended conferences, the work of the Association of interest to the members represented was reviewed by the staff and there followed a general discussion on the work and on its industrial application. Secondly, arising from a recommendation at the first of these conferences, a monthly *Research Supplement* to the *B.N.F.M.R.A. Bulletin* has been introduced. This *Supplement*, which is confidential to members, contains summaries in relatively non-technical language, of the Association's detailed research reports. The summaries aim to state clearly the ultimate objective of the work reported and its relation to a particular industrial problem. The experimental methods used are treated briefly, but the results are given in some detail, especially when they are capable of immediate practical application. The help of the Association's staff to assist members in such practical application, is offered. For all who wish, the full reports are available as before, but the monthly *Research Supplement* enables members to see quickly the results of all the current work of the Association and pick out for special study items of immediate interest.

The general publication policy of the Association is on a broader basis than before. The research results of the Association remain, and always will remain, confidential to members for a limited period, the length of which will vary with the nature of the work. On the whole, however, more work is now being eventually published in the Journals of Scientific Societies and in the technical press, and in the case of investigations

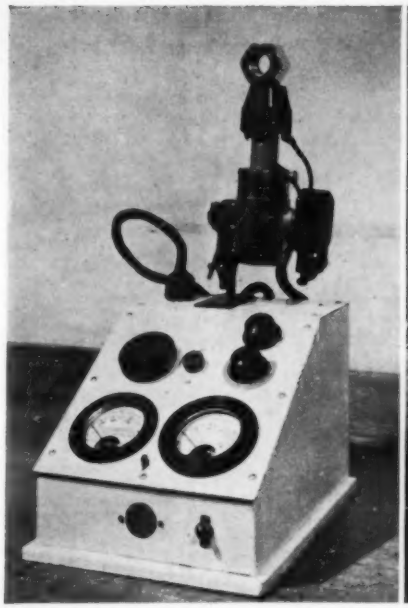


Fig. 1.—Surface reflectometer for comparing polished surfaces.

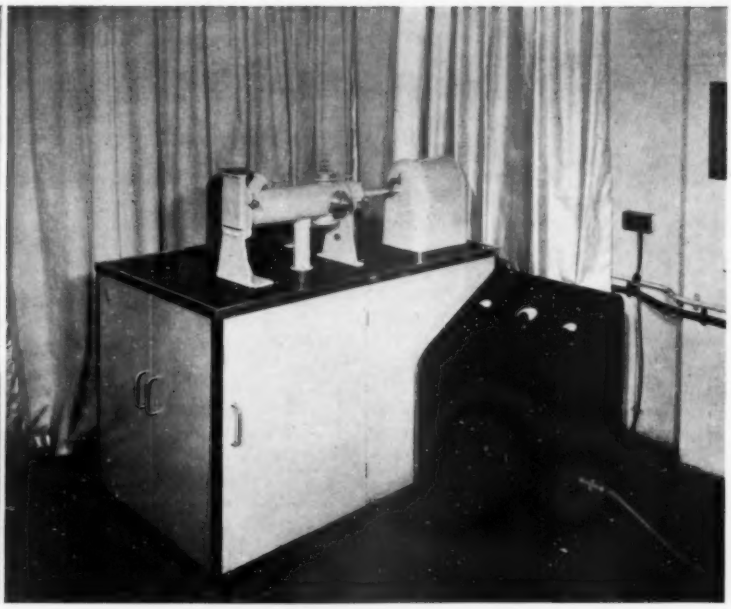


Fig. 2.—Electron diffraction camera.

the results of which are of general theoretical interest or are concerned with research techniques and apparatus, the period of confidential release to members may be as short as a matter of months. This policy, it is hoped, will make the work of the Association more widely known, especially overseas.

Research Developments

It is not intended in this article to give a complete picture of the research effort of the Association, but the following notes and references to published papers will indicate the scope of some recent work.

It will be appreciated that the B.N.F.M.R.A. serves an industry covering a wide metallurgical field. Few items on the research programme are therefore of interest to all members, though some researches, for example that on spectrographic analysis, are treated as general researches. There are four industry committees representing the main groups of members (the copper-nickel industry, the aluminium-magnesium industry, the lead-tin industry and the zinc and galvanising industry) responsible for deciding the Association's research policy for their respective industry, subject to the over-riding control and guidance of the Research Board which also takes responsibility for the general researches. For convenience, the following notes will be grouped under industry headings, though it must be emphasised that in the organisation of the Association's own staff, a subject rather than an industry grouping is followed. Thus in any one research section investigations may be in progress of interest to several of the industry groups and there is the maximum opportunity for points arising from the work on one research to be applied immediately to an investigation on another metal. For example, there are in progress in the corrosion section researches for three of the four industry groups.

General Researches

Spectrographic analysis.—The general purpose source unit for spectrographic analysis which was developed in the Association's laboratories and described some years ago, has now been applied to the analysis of a variety of non-ferrous metals and alloys, and the techniques and recommended methods employed have been described in a recent article[1].

For some time, the possibilities of multiplier photocells, both as research tools and as replacements for the photographic plate, have been studied[2]. From their use, considerable evidence has been gained that the normal arcs or spark discharges used in spectrographic work give variation in the instantaneous light intensity of spectra, even when excited by a source unit of constant electrical characteristics. Therefore, a preliminary examination has been made of the possibility of developing a demountable low pressure discharge tube in the hope that this type of discharge may be capable of application in metallurgical analysis. At the moment, however, most attention is being given in this research to the development of a simplified form of recording spectrograph and a greatly improved design of adaptor for mounting photocells has been made. The use of this, coupled with the application of a technique recently developed for the quick focussing of photocells on different lines of the spectrum, will it is hoped, permit the development of direct recording techniques on standard spectrographs.

Metal finishing.—A simple instrument for comparing the standard of polish on flat metal surfaces has been developed in the Association's laboratories[3]. This depends for its operation on the passage of a parallel beam of light through a hole in the centre of a disc shaped photocell. The beam of light falls normally on the surface to be examined and, depending on the

1 Beale, P. T., "Spectrographic Analysis: Use of the General-Purpose Source Unit for Non-Ferrous Metals and Alloys," *Metal Industry*, July 15, 1949, **75**, (3), 43-45, 49.
2 Nicol, J., "Multiplier Photo-cells: Characteristics with Particular Reference to Their Application in Spectrographic Analysis," *Metal Treatment and Drop Forging*, Winter, 1948-49, **15**, (56), 217-223.
3 Ollard, E. A., "Surface Reflectometer for Evaluating Polished Surfaces," *J. Electrodepositors Tech. Soc.*, 1949, **24**, 1-8.

degree of roughness of the surface, a proportion of the light is scattered and falls on the surface of the photocell. It has been found that this instrument will place polished surfaces in the same order as that obtained by visual inspection and it is being used in connection with the Association's general research on electropolishing of non-ferrous metals.

In addition to this general research on electropolishing, the metal finishing section is investigating electrodeposition on aluminium and its alloys and providing technical assistance to members interested in electrodeposition, anodising and other similar finishing processes. A recent agreement between the B.N.F.M.R.A. and the Metal Finishing Association has increased the membership from this industry.

Electron diffraction.—An electron diffraction camera has been constructed in the Association's workshop and is illustrated in Fig. 2. This has already found a useful application in several of the Association's researches. The camera has been made with a horizontal body to permit the examination of surfaces of molten metals, the containers for which can be introduced through a port underneath the apparatus. This camera uses the same high tension supply as the electron microscope installed in the Association's physics section some time ago.

Copper-Nickel Industry

Casting.—The laboratory investigation of problems connected with the production of bronze and gunmetal castings is completed, and the research has reached the stage of practical application in members' foundries. Apart from a better general understanding of all the problems involved in the production of satisfactory castings, the results of the Association's work have provided a useful practical technique for the production of pressure-tight bronze and gunmetal castings. This is based on the improved distribution of skrinkage porosity made possible by controlled gas absorption resulting from reaction between the molten metal and moisture in the sand mould (metal/mould reaction). When tried out on practical scale in members' foundries, this technique was successful in reducing the number of castings, of particular types, which had to be rejected because of leakage under pressure test. Further industrial application of the process is anticipated.

The results of the Association's study of melting and casting problems are to a large extent applicable to the casting of shapes for subsequent working as well as to sand casting. This was made clear in an introductory paper[4] to the recent Institute of Metals Symposium on this subject. The implications for the wrought non-ferrous metal industry of work subsequent to that published in the well-known " Casting of Brass Ingots " was reviewed.

Corrosion.—The problem of localised pitting corrosion of copper pipes in domestic plumbing systems carrying certain types of water is still under investigation. In addition to field trials of copper and copper alloy pipes, some progress has been made with the development of a laboratory test from which the action of a particular water supply on copper can be forecast.

In some districts, the deterioration of ball valves in domestic plumbing systems causes inconvenience to the householder and wastage of water. An investigation was carried out in collaboration with the Water Pollution Research Laboratory and the results have been published[5].

A considerable proportion of the effort of the corrosion section continues to be devoted to the study of the behaviour of copper-base alloys in moving aerated sea-water, the conditions of use which exist in marine condenser systems. In view of the demand for condenser tube materials capable of withstanding higher water speeds than those hitherto in use, the behaviour of copper-base alloys is being examined under impingement conditions at water speeds in excess of 15 ft./sec., which has been the standard water speed used in the laboratory testing equipment for many years. The importance of micro-organisms as promoters and accelerators of metallic corrosion in this and other of the Association's researches has been recently reviewed[6].

The results of the Association's study of the inter-crystalline failure of brasses in various corrosive environments were summarised in an article in this JOURNAL,[7] and work on this research continues with the development of a theory of a possible mechanism for delayed fracture under prolonged stress. Preliminary trials of remedial measures for inter-crystalline weakness which this theory has suggested have given promising results both in this and in other researches in which the intercrystalline failure of metals in creep or on hot working is being studied.

Creep and fatigue of copper-base alloys.—Much work on the above subject is in progress in the mechanical testing section. Breakdown of electrical generating

4 Bailey, G. L. and Baker, W. A., " Melting and Casting of Non-Ferrous Metals," *J. Inst. Metals*, Jan., 1949, **75** (5), 285–310.

5 Ingleson, H., Sage, A. M., Wilkinson, R., " The Effect of the Chlorination of Drinking Water on Brass Fittings," *J. Inst. Water, Eng.*, Jan., 1949, **3** (1), 81–91.

6 Rogers, T. H., " The Promotion and Acceleration of Metallic Corrosion by Micro-Organisms," *J. Inst. Metals*, September, 1948, **75** (1), 19–38.

7 Whitaker, M. E., " Intercrystalline Failure of Brasses and Aluminium Brasses in Air, Ammonia, and Certain Aqueous Solutions and Molten Metals," (Summarising experimental work by E. Voce and A. R. Bailey), *Metallurgia*, Nov., Dec., 1948, **39** (229–230), 21–29, 66–70.

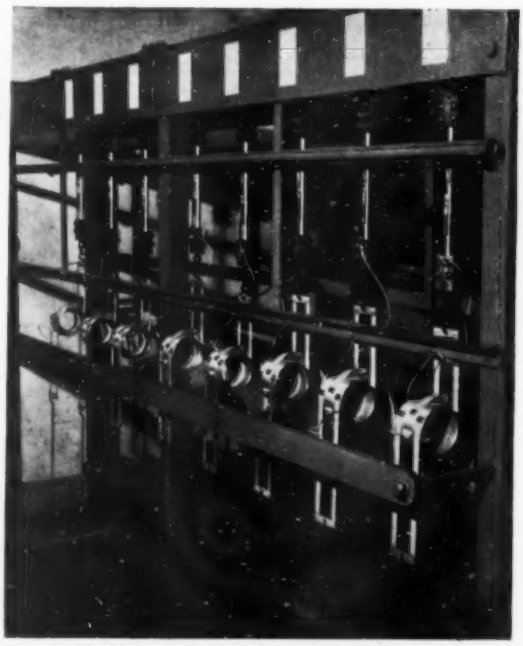


Fig. 3.—The frame used for constant stress creep tests on lead alloys.

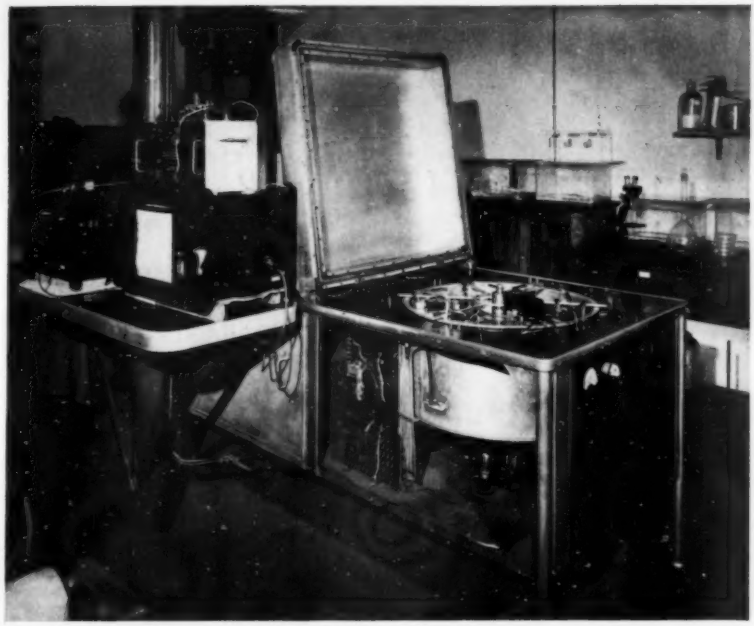


Fig. 4.—Laboratory thermostat used for corrosion tests ; continuous records of potentials and corrosion currents can be made.

plant has occurred in recent years due to the phenomenon known as "copper shortening." This may occur in large turbo-alternators due to the differential expansion of the copper windings and the steel rotor body and to the fact that centrifugal forces restrict the expansion at operating speeds. The results obtained from a research on the creep of high conductivity copper strip suggest that if the adoption of silver-bearing coppers with a certain amount of cold work does not in practice eliminate or substantially reduce troubles due to copper shortening ,the solution of the turbo-alternator rotor winding problem would appear to lie in some direction other then that of materials with improved creep properties. The creep and high temperature fatigue properties of a number of copper-base alloys are being surveyed partly for the Ministry of Supply and partly in connection with the development of copper-base alloys suitable for gas turbine heat exchangers. The rotating load high temperature fatigue testing machine described in this JOURNAL a year ago[8] is being used in this work. Twelve such units are now installed in the Association's laboratories.

Aluminium-Magnesium Industry

Considerable progress has been made in the study of the mechanism of grain refinement of aluminium alloys and a theory of the process, which accounts for the observed effects resulting from the use of commercial grain refining treatments, has been developed following the identification of the factors responsible for grain refinement. This theory will be discussed in a paper shortly to be published. The ideas developed are capable of application to the grain refinement of other metals and also suggest that more efficient grain refining agents for aluminium alloys can be prepared.

The Association's recommendations regarding the gas welding of aluminium-magnesium alloys have been published[9] and it has been shown that material containing up to 7% magnesium can be satisfactorily welded without loss of strength due to blistering and gas porosity at the junction of the weld bead and the parent metal, providing that meterial of low gas content is used. This low gas content can be achieved by attention to production conditions including the avoidance of contamination by certain alkaline earth metals which may be introduced from melting fluxes. A rapid test for checking the gas content of material of welding quality has been described[10] in which the presence of gas is detected by the examination of specimens heated for a time in a molten bath of sodium dichromate. This method has been calibrated by actual estimation of the gas extracted from test specimens.

New researches recently started include an investigation of the corrosion of aluminium and aluminium alloys in supply waters and a fundamental study of the metallurgical features responsible for the development of distortion bands during the deep drawing of certain aluminium alloys.

Lead-Tin Industry

The main research of interest to this industry group is a fundamental investigation of the creep and fatigue properties of lead alloys. Some difficulty has been experienced in obtaining material which will give sufficiently reproducible results to enable the fundamental investigation of the metallurgical factors influencing creep and fatigue to proceed, but a satisfactory degree of reproducibility has now been obtained from specimens extruded on a small experimental extrusion press. The investigation will comprise the study of creep and fatigue characteristics of alloys chosen to represent different metallurgical conditions ; an alloying element in solid solution, a precipitation hardening alloy, and so on. In view of the profound effect on the creep of lead of small proportions of impurities, a special high purity lead has been obtained to form the basis material for this work. In order that the results of creep tests shall be capable of mathematical treatment and correlation with theoretical studies carried out by other workers, most of the tests will be carried out under constant stress conditions. A special lever mechanism has been designed which enables constant stress to be maintained during the period that specimens are undergoing general elongation.

A new research has the primary object of improving the quality of commercially extruded lead pipe as used in chemical plant and in plumbing. As a first step, a survey is being made of the existing practice in the works

8 McKeown, J., and Back, L. H., "A Rotating-Load, Elevated-Temperature Fatigue Testing Machine," *Metallurgia*, September, 1948, **38** (227), 247–254.

9 Liddiard, E. A. G., "The Welding of Aluminium-Magnesium Alloys," *Sheet Met. Ind.*, September, 1947, **24** (245), 1857–1860, 1862.

10 Swain, A. J., "A Rapid Method for Estimating the Hydrogen Content of Wrought Aluminium Alloys," *J. Inst. Metals*, July, 1949, **75** (11), 863–868.

of members and when this is complete it is intended to use the resulting information to plan a programme of research on an experimental extrusion press fitted as a sub-press to the new 500 ton hydraulic press.

The Association's research on soldering and brazing continues on fundamental lines, studying the physical factors involved in the spreading of a liquid metal on a solid metal, but an important improvement to one metal coating process, for which provisional patent protection is being sought in the interest of members, has already emerged from this study. The Association's work during the war in connection with the campaign to economise in the use of tin in solders, led to the collection of useful information on mechanical properties of soldered joints which is capable of wide general application. The results of this work have been summarised in a recent book published by the Association[11].

Zinc and Galvanising

The resistance to corrosion of galvanised steel by hot water is greatly affected by the reversal of polarity which occurs in some waters at about 60° C. (140° F.), a common temperature of operation of domestic hot water storage tanks. Owing to changes in the film formed on the zinc surface in this temperature range, the zinc will no longer afford protection from corrosion to small areas of exposed steel, and in fact, the corrosion of the steel is accelerated. Such a mechanism is one of the factors responsible for the occasional rapid failure of galvanised steel hot water storage tanks. A paper has been published[12] describing in detail the theoretical work on which this conclusion has been based. The research work has continued with the development of coatings more resistant to penetration by hot water and it is hoped that full scale trials of the coatings of recommended composition will soon be put in hand. Fig. 4 shows the laboratory thermostat specially constructed for this work. Specimens of galvanised steel contained in flasks of water were placed in this thermostat and continuous records could be made of corrosion currents and potential changes.

The study of the white rust corrosion of zinc and galvanised steel, that is the formation of copious white corrosion products which can rapidly destroy the protective zinc coating has been concluded. A simple protective treatment has been recommended to members which should be effective in reducing the dangers of this type of corrosion, which often occurs when galvanised goods are stored or transported under humid conditions.

The Association has resumed work on the galvanising process in a new research designed to find ways and means of reducing the metal losses from the formation of zinc oxide ash and iron-zinc alloy dross.

11 McKeown, J., "The Properties of Soft Solders and Soldered Joints," B.N.F.M.R.A. Research Monograph, No. 5, published 1948.

12 Gilbert, P. T., "An Investigation into the Corrosion of Zinc and Zinc-Coated Steel in Hot Waters," *Sheet Met. Ind.*, Oct., Nov., Dec., 1948, **25** (258–260), 2.03–2012, 2243–2254, 2441–2448, 2460.

In addition to the papers mentioned in the text, the following additional work was also published.

Hallowes, A. P. C., "The Working Behaviour of Phosphorous-Deoxidised Coppers Containing Bismuth," *J. Inst. Metals*, September, 1948, **75** (1), 1–18.

Baker, W. A., and Hallowes, A. P. C., "The Elimination by Lithium of Bismuth Embrittlement in Deoxidised Coppers and Copper Alloys," *J. Inst. Metals*, May, 1949, **75** (9), 741–758.

Hallowes, A. P. C., "The Embrittlement of Tough-Pitch Copper by Bismuth," *J. Inst. Metals*, June, 1949, **75** (10), 839–854.

Baker, W. A., and Hallowes, A. P. C., "Experiments on the Removal of Selenium and Tellurium from Blister and Fire-Refined Copper," *Bull. Inst. Min. Met.*, August, 1949, No. 513, 1–14.

Adams, D. E., "Segregation in Aluminium-Copper Alloys," *J. Inst. Metals*, June, 1949, **75** (10), 809–838.

Tylecote, R. F., "The Pressure-Butt Welding of Light Alloy Bar," *Welding Research* (Supplement to *Trans. Inst. Welding*), February, 1949, **3** (1), 2r–16r.

Tylecote, R. F., "Further Investigations on the Pressure Welding of Light Alloy Sheet," *Welding Research* (Supplement to *Trans. Inst. Welding*), October, 1948, **2** (5), 94r–108r.

Pendleton, J. "Gas Welds in a High Strength Aluminium-Zinc-Magnesium-Copper Alloy," *Welding Research* (Supplement to *Trans. Inst. Welding*), Oct. 1948, **2** (5), 87r–93r.

The British Cast Iron Research Association

By Dr. J. G. Pearce, Director.

Not every year can announcements be made of such spectacular developments as the Association's cerium-treatment process for the production of irons containing nodular graphite in the as-cast state. Nevertheless progress is continuous in the development of cast iron as an engineering material and mention is made of some of the subjects under investigation. Arrangements have now been made whereby any producer of iron castings in the United Kingdom can become a full member of the Association by the exercise of a simple formality, and those who have not yet taken advantage of the position would be well advised to give the matter serious consideration.

THE middle of 1948 brought a profound change in the status of the British Cast Iron Research Association. From that date, and by an arrangement made between the Association and the Joint Iron Council, it became possible for any producer of iron castings in the United Kingdom to become a full member of the Association by exercising a simple formality. At that time the Association had about 500 members and this figure has now been doubled by the steady influx of new members. There is, however, a considerable balance who still require to act, as the total number of ironfoundries in the United Kingdom is estimated at about 1,800.

The Council has considerably modified its Committee structure and further improvements in this are contemplated. The income of the Association has been practically doubled and the possibilities for extending the programme are consequently bright. Accommodation and equipment, however, in that order, are needed before any considerable staff extension can take place. At the present time, new laboratories are in process of erection for mechanical testing and for a machine and instrument shop. The Scottish Laboratory, housed for so many years at Falkirk, has recently, by a unanimous decision of the Scottish Committee, and approved by the Council, been transferred to Glasgow, consequent on the termination of the lease of the Falkirk premises. Long-term plans are being prepared, based on a future total income of £100,000 per annum and a staff about double its present figure.

Fig. 1.—A flat strip of nodulised cast iron, 1¼ in. wide, ×⅛ in. thick, annealed and bent cold to the shape shown without fracture.

Nodular Cast Iron

As far as the work is concerned, the announcement by the Association in the early part of 1948 of the discovery of a process for the production of nodular graphite iron might well be described as the metallurgical sensation of that year. The Association's process essentially consists of the addition to an appropriate low sulphur, low phosphorus, hyper-eutectic iron, of a small amount of cerium in the form of *mischmetall*. The cerium desulphurises and the balance of it carbide-stabilises and the breakdown of this carbide produces the graphite in a nodular or spherulitic form. This structure can be obtained in the as-cast state and spectacular improvements in the mechanical properties result[1], particularly in shock strength, ductility and elongation, and a comparatively short anneal suffices to improve these still further.

It will be recalled that ordinary engineering machinable grey iron contains free graphite in the form of flat plates, usually known as flakes. The carbon over and above that found in steel is required to make the material castable at comparatively low temperatures. If the iron is cast in the white, unmachinable state, with the carbon in the form of iron carbide, it can be annealed, as in the malleable annealing process, and the carbon then exists in the form of nodules of so-called temper carbon. In the as-cast state, nodular graphite iron represents a product in between these two and virtually offers an entirely new material to the engineer. An illustration will suffice: the ring shown in Fig. 1 is a flat strip of nodular graphite iron ⅛ in. thick and 1¼ in. wide, given a simple short anneal and then bent cold to the shape shown without any sign of distress or fracture. Samples and further illustrations are on view at the Engineering and Marine Exhibition at Olympia.

American recognition of the value of this discovery has been swift and various authorities have paid tribute to the remarkable character of the work. In the discussion following the presentation of papers to the Iron and Steel Institute[2] and to the American Foundrymen's Society[3] in the States, representatives of the Mond Nickel Co., Ltd., and the International Nickel Co. announced that they had produced similar results by the use of magnesium. Naturally, a good deal of development is proceeding and the possibilities of nodulising by the use of other elements has not been forgotten. This work has also thrown a considerable amount of experimental work on other departments of the Association, and notably for the evaluation of methods for the analytical determination of small quantities of cerium[4] and magnesium in ferrous metals, and the spectroscopic analysis for similar elements. Incidentally, an interesting advance has been made in spectroscopic analysis[5] to simplify the method of photographic evaluation, which enables users to relax the standardisation of photographic processing. The method appears to be of universal application in this field.

1 Morrogh, H., and Grant, J. W., *Proceedings, Institute of British Foundrymen*, 1947–48, **41**, pp. A29–A53.

Other work in progress

Among other fundamental work approaching completion is a study of the iron-carbon-phosphorus system and a study of the effects of small amounts of elements, particularly oxygen and sulphur, on pure iron-carbon alloys. Some useful results have emerged from work on rate of heating of whiteheart malleable cast iron. Other work in progress covers slag-metal reactions and the fluidity of cast iron with special reference to light castings. Progress has also been made on the corrosion and erosion of cast iron propellers, being done in conjunction with the British Shipbuilding Research Association, and the apparatus employed is featured at the current Engineering and Marine Exhibition at Olympia, together with a suitable accompanying film. A large amount of work has also been done on the properties of the new irons and relations of tests to one another.

Work on moulding sands continues to be extremely active and the Association is holding a Conference at the end of September exclusively on this subject. The problem of fuel, particularly British metallurgical coke, has also engaged the attention of the Association during the year and a Conference exclusively devoted to this was also held in April, 1949. The quality of metallurgical coke for cupola melting has a most important influence on the quality of British iron castings, and also upon the economy with which they can be produced.

2 Morrogh, H., and Williams, W. J., *Journal of the Iron and Steel Institute*, 1948, **158**, March, pp. 306–322.
3 Morrogh, H., *Transactions of the American Foundrymen's Society*. 1948, **56**, pp. 72–90.
4 Westwood, W., and Mayer, A., *Analyst*, 1948, **73**, pp. 275–282.
5 Argyle, A., and Price, J., *Journal of the Society of Chemical Industry*, 1948, **67**, May, pp. 187–190.

Electrodepositors' Technical Society

A PAPER on "The Disposal of Plating Shop Effluents," will be presented by Mr. A. E. J. Pettet, B.A.,M.Inst.,S.P., at a meeting to be held at 6-0 p.m., October 17th, at the Northampton Polytechnic, St. John Street, Clerkenwell, London, E.C.1. The author is a member of the staff of the Water Pollution Research Board of the Department of Scientific and Industrial Research.

Non-members are invited but, to prevent disappointment which would arise, if the attendance exceeded the seating capacity of the lecture room, those intending to be present are advised to notify the Hon. Secretary of the London Centre Committee, W. E. Cattley, 13a, Highlands Avenue, Acton, London, W.3., as early as possible.

The British Ceramic Research Association

By A. E. Dodd, M.Sc., F.R.I.C.
(*Head of the Information Department*).

There is no doubt that the solution of the problems associated with the all-basic open-hearth steel furnace will have far-reaching repercussions for the steel industry, as the adoption of such furnaces should lead to increased output and reduced costs. As a result of a joint study of the problems by the British Ceramic Research Association and the British Iron and Steel Research Association, preliminary recommendations have been tabled for the guidance of those concerned and a number of furnaces have been put into operation.

PROBABLY the most interesting item during the past year relating to the use of refractories in the British metal industries had been the construction of several all-basic open-hearth steel furnaces. It should be understood, however, that these were not the first steel furnaces with basic roofs to be built in this country, and in Germany the basic roof has become almost standard practice at certain steelworks by the early years of the war. The German lead is attributable to two factors: first the availability in Central Europe and Turkey of abundant supplies of high-quality magnesite and chrome ore—neither of which occurs naturally in Britain—and second the relatively easy conditions imposed on many German furnaces in consequence of the use of a high proportion of hot metal previously blown in converters. Nevertheless, success with basic roofs was not immediate even under these conditions. In 1935 it was stated in a German journal that magnesite and chrome-magnesite roofs had been built on a 40-ton Hoesch furnace. The first magnesite roof collapsed after 174 heats and the second after 259 heats; the poor life was attributed to shrinkage and the fact that the roof did not weld into a monolith. A chrome-magnesite roof was more successful.

Advantages of the Basic roof

Some of the advantages to be expected from the use of a basic roof are as follows:

1. Increased output due to the faster working made possible by the higher temperature that the basic roof will withstand. There should be less shut-down time and, in consequence, a reduction in the overheads both in the melting shop and in the mill.
2. A reduction in over-all steelmaking costs.
3. A reduction in the man-hours required for bricklaying.
4. Less slag bulk on account of the elimination of silica drip.
5. The possibility of realising the full advantages of liquid fuels.

The question of the elimination of silica drip may be more important than would at first be imagined. It has been estimated that as much as 0·03 in. of the silica roof bricks may be lost each heat; in a fairly large furnace this would be equivalent to the loss of over 250 lb. of silica, and if it is assumed that this silica drips into the bath it may be shown that at least 500 lb. more lime will be needed to keep the slag sufficiently basic to hold the phosphorus and sulphur.

Practical Experience

The first chrome-magnesite roofs built over British furnaces had relatively short lives. The same types of refractory were used as were most generally used in Germany; nevertheless, two of the furnaces had lives of only about 300 heats even though they were driven very little faster than furnaces with silica roofs. Experience in the operation of these roofs and improved design did lead to improved roof lives but on the outbreak of war the all-basic furnace in this country was still very much an experimental unit, and only four or five steelworks had made trials. Owing to the high cost of the chrome-magnesite bricks compared with the cost of silica bricks, most of the roofs were uneconomic. Yet a certain amount of useful experience had been gained before the experiments had to be discontinued owing to the war. To keep the position attained in this country in its true perspective, it may be mentioned that it was not until 1940 that the first all-basic open-hearth furnace was built in the U.S.A.

Although the war called a halt to full-scale trials of basic roofs, it gave an impetus to laboratory studies on the causes of the breakdown of chrome-magnesite bricks under service conditions; this research was outlined in the review of the Research Association's work published in *Metallurgia* in 1946. In January, 1947, a sub-committee was set up to promote research on, and development of, the all-basic furnace. It was formed as a joint committee of the British Ceramic Research Association and the British Iron and Steel Research Association; its personnel included technical representatives of firms making chrome-magnesite bricks and of steelworks immediately interested in all-basic furnaces. Under the chairmanship of Dr. J. H. Chesters, of the Research and Development Department of the United Steel Companies, Ltd., good progress was made, and in less then twelve months preliminary recommendations were made available for the guidance of firms intending to make chrome-magnesite bricks of roof quality, and of steelworks intending to build all-basic furnaces. The speed with which concrete recommendations could be put forward was a result of the war-time research carried out by the Association on chrome ores and the co-operative efforts of manufacturers who produced under industrial conditions special quality chrome-magnesite bricks from selected raw materials.

Recent Research

Other research data on basic refractories released during the year include the results of an investigation of the $CaO\text{-}Cr_2O_3$ system[1]. An important finding has been that the system is not binary unless oxygen is

1 Ford, W. F., and Rees, W. J., "The CaO-MgO-Cr_2O_3 Ternary System," (*Trans. Brit. Ceram. Soc.*, **47**, 207, 1948), **48**, 291, 1949.

excluded; oxidation takes place at relatively low temperatures and tetragonal calcium chromate is formed. In the presence of excess lime, calcium chromate loses oxygen at 800° C. and a ternary compound is formed—$9CaO \cdot 4CrO_3Cr_2O_3$. This product of oxidation melts congruently at 1,228° C. under atmospheric oxygen pressure, and the eutectic between it and lime melts at 1,174° C. Calcium chromate alone or in the presence of excess chromic oxide, dissociates at 1,022° C. with loss of oxygen to form a liquid and the true binary compound, $CaO \cdot Cr_2O_3$; this calcium chromate has a high melting point, but at temperatures below 1,022° C. it is slowly oxidised to calcium chromate and chromic oxide.

The significance of this work lies in the explanation that it affords of the relatively poor behaviour of chrome-dolomite bricks in service. There are vast dolomite deposits in this country. Burned dolomite is excellent as a hearth material provided that it can be used soon after it has been burned and provided the furnace is never cooled for long periods. The stabilisation of dolomite has, of course, been achieved by clinkering with siliceous minerals such as serpentine, which combine with the free lime and so prevent subsequent slaking; stabilised and semi-stabilised dolomite bricks give good service in many of the steel works of this country. It was thought that chrome ore might also serve as a stabiliser for dolomite and so, in fact, it will; chrome-dolomite refractories, however, have a low refractoriness-under-load, and this study of the CaO–Cr_2O_3 system has shown that the cause is the low melting points of the oxidation products.

The British Welding Research Association

By W. K. B. Marshall, B.Eng., A.I.M.

Assistant Director of Research

The work of this Association is progressing at an enhanced rate not only in presenting results from various investigations undertaken but in ensuring that the broad implications of the work done are understood by industry generally. This report summarises a selected few of the fields of activity in which co-operative research is solving problems and improving techniques which are leading to the wider use of welding in industry.

SINCE the last survey of the work of the B.W.R.A. appeared in this journal 12 months ago, steady progress has been made both in the work on the various investigations and in building up equipment and resources. Much of the work has reached the reporting stage and the results have been made available to the public through the Association's own journal *Welding Research* and the technical press.

The duties of a Research Association to the Industry it serves however, do not end with the publication of results. It is inevitable that the detailed results of researches are read and assimilated by relatively few people, and in common with other Research Associations, the B.W.R.A. has the task of ensuring that the broad implications of its researches are fully understood by industry generally. It also has the task of seeing that industry makes the maximum use of the Association's resources in solving the day to day problems which arise.

The Association had these points in mind, when in March this year, it organised, in collaboration with the Institute of Welding, a conference on "Welding as an aid to economy in Steel and Manpower," and when later in the year it increased the size of its Technical Liaison Department.

The conference which was held at Ashorne Hill, was well supported by industry. Various well-known engineers presented papers on the economies that could be effected by the use of welding in machine tool construction, shipbuilding, railways and constructional engineering. These papers showed quite conclusively that welding was in fact saving considerable quantities of steel, and in many cases could reduce the man-hours required to do the job. Recommendations emerged from the conference which have been actively followed up by the Association and other appropriate bodies with whom it is in touch.

The problem of strengthening the Technical Liaison Department is one which the Association has had in mind for some time, but the need to use the limited funds available on direct research work, has so far made it difficult to do anything about it. However, due to a recent revision in the terms of the grant which the Association receives from the Department of Industrial and Scientific Research, funds have become available which have enabled the necessary improvements to be put into effect. A strong team of engineers has been built up whose function is to bring news of the Association's researches to members, and to assist in the day to day problems concerned with welding which arise in industry. Already it is quite clear, from the diverse technical enquiries received by the Association, that the Staff, with their special knowledge of welding, can be of immense help in solving the many irritating difficulties which are interfering with the achievement of maximum productivity.

As far as the Association's research programme is concerned, the emphasis is little changed from last year and the same sub-divisions will be adhered to as previously. It is assumed that the reader is already familiar with the origin of the various investigations and such details will not be repeated here.

Constitution of Weld Metal

The high temperature tensile tests in the platinum wound vacuum furnace have shown certain anomalies in the properties of weld metal at high temperature which it is felt may be characteristic of cast steel in general, but which, due to the conditions of test, may not be directly related to the hot-cracking of welds experienced in practice. It is proposed therefore, to extend the work so that the conditions of test more nearly approach those which occur during welding. Work is also being directed towards determining at what

temperature welding cracks occur, since it is felt that this information might throw some light on the cause of cracking. During the year, work on the well known T-test has been completed and the factors affecting the consistency of results in this test have been disclosed.

Further co-operative work on the causes of haloes in weld metal has given additional information on the relation between this defect and the hydrogen content of the weld. A programme of investigation has been drawn up aimed at elucidating the exact mechanism of the effect.

Weldability of High Strength Structural Steels

As a result of a painstaking investigation into the weldability and mechanical properties of about 30 high strength structural steels, it has been possible to choose two of the more promising steels for further large scale tests. Two ton melts of these steels are being cast and ingots rolled to representative thicknesses to enable a variety of tests to be carried out. During the course of work on this range of steels, a weldability test has been developed which, it is felt, may provide a cheaper and simpler means of assessing the tendency of a steel to give hard-zone cracks than the more traditional tests.

The Welding of Non-Ferrous Metals

The main effort in this section has been directed to the welding of thick plate in aluminium-magnesium alloy. The original tests on metal arc welds in 1 in. thick aluminium—5% magnesium alloy disclosed many factors which may influence the strength of welds in these alloys. A form of porosity was encountered which is thought to be connected with the gas content of the parent plate and of the electrodes and an investigation is now proceeding with a view to determining the strength of metal arc welds in alloys in which the gas content of the materials used is controlled at a low level.

Work has also been started on the welding of aluminium-magnesium and aluminium-magnesium silicide alloys by the argon arc process. As a preliminary, the Association has been co-operating with the Electrical Research Association in an investigation of the characteristics of the tungsten-aluminium arc in argon. This research has already yielded some very interesting results of immediate practical importance.

The weldability tests on a range of magnesium-rich alloys are now well advanced. The cracking tests have been completed and the tensile properties of the welds are being determined in collaboration with the N.P.L.

Application of Welding to Structures

The work on the behaviour of welded rigid frame structures which is being carried out at the Engineering Laboratories of University of Cambridge under Professor Baker, and at the B.W.R.A. Research Station at Abington, has now reached a very interesting stage. The laboratory tests in connection with the simple plastic theory have been supplemented by tests on full-scale structures. The method of testing these structures was described in detail in the last survey, and a general view of a structure under test is shown in Fig. 1. Three types of portal frame structures have been tested under side and vertical loads. Two of these had rigidly connected staunchion bases, whilst the third had pinned bases. The actual collapse load of the structures showed good agreement with the calculated values based on the plastic theory.

In parallel with the full scale investigations, an extensive series of laboratory tests is proceeding with the object of providing data to enable a comprehensive design method to be established. This laboratory work is concerned with the behaviour of simply supported and continuous beams, and miniature frames under various methods of loading, and includes, amongst other things, an investigation into the factors which affect the lateral stability of structural members.

A design method for single frame portals is already available, and sufficient data has been accumulated to allow the theory to be extended to the design of two or three bay pitched portal structures. It is gratifying to note in this connection, that mainly as a result of this work, British Standard 449 covering the design of welded structures has been amended during the year to permit of the use of a design factor based on the collapse load of the structure, in addition to the more normal design criterion based on the yield point of the material of construction.

Dynamic Loading of Welded Structures

The resonance vibration fatigue method which subjects the specimen to bending fatigue has been in considerable use during the year on various types of welded stiffened panels representative of ships construction. The object of the investigation is to determine the best type of stiffener joint detail under conditions of fatigue loading. It is intended to extend this work to the testing of other items of ships' construction.

Following the success in applying the resonance vibration method to fatigue in bending, an attempt has been made to use the method for inducing longitudinal vibrations. A preliminary test has shown this to be possible, and it is hoped to investigate the fatigue strength of various members in this way.

The investigation into the effect of residual stresses on fatigue strength is continuing, but some difficulty has been experienced initially in inducing regular residual stress patterns in the rectangular section specimens. A satisfactory method of measuring residual stresses by sub-division has been established.

Another problem which has received attention is the effect of welding faults on the fatigue endurance of joints. A preliminary investigation has been initiated by the Admiralty with a view in the first instance to establishing the effect on the fatigue strength of butt-welds of certain types of welding defects visible from radiographs.

The work may eventually be extended to cover other joints commonly used in shipbuilding and general construction.

The importance of the work on fatigue properties has led to the Association contemplating the purchase of a large fatigue testing machine of the hydraulic pulsating type which will enable virtually full-size specimens to be examined under fatigue loading. An appeal to industry has been made with a view to raising the necessary funds for this machine.

Pressure Vessels and Pipe Lines

A series of investigations into the stresses induced in pipe bends under different types of loadings has been completed during the year. The loading comprised internal pressure and external compression, whilst tests

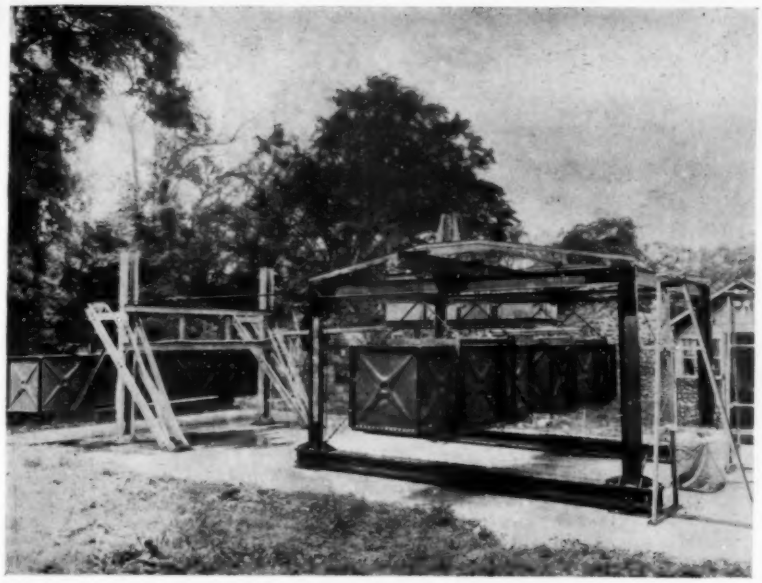


Fig. 1.—Full-size Portal frame structure undergoing test at the Abington Research Station.

under a combination of these conditions are now in progress. Some interesting information was obtained on the distribution of stresses in both seamless and welded bends. Amongst other things, it was established that, providing the welding is carried out satisfactorily, welded bends should be able to stand the same static pressure as seamless bends.

The full-size pressure vessel with various types of openings mentioned in the last survey has now been received, and is at present under test. An investigation into the stresses occurring in the neighbourhood of branch connections is being made with a view to obtaining information on the re-inforcement necessary at these points.

It is intended that the work on pipe lines and pressure vessels should be extended to include the effect of pulsating stresses on such equipment. The Association is accordingly making arrangements to purchase a special piece of equipment which is capable of applying very heavy pulsating pressure. The cost of this equipment is being very generously subscribed by members and friends of the Association.

During the year the Committee concerned has completed the preparation of the memorandum on the recommendations for arc welding butt joints in pipe lines, and this document will shortly be issued to members.

Resistance Welding

In its work on resistance welding, the Association has in the past depended on the goodwill of its members who have kindly put their machines at the disposal of the research workers. Under this arrangement, some very good work has been done, but there are obvious drawbacks which are now happily overcome by the establishment of a resistance welding section at the Abington Research Station. Here, a number of machines have been installed for the spot welding of light alloys and steels.

Until this new section gets thoroughly under way however, a certain amount of co-operative research is still continuing. This is mainly concerned with the projection welding of mild steel and the resistance welding of studs to sheet. The work on projection welding has provided a basis for a code of practice on this form of welding which is at present in course of preparation.

During the year a code of practice for the spot welding of low carbon steels has been published, and has been well received by Industry. Work continues on the development of equipment for measuring the main variables of spot welding such as electrode pressure and secondary current, etc.

A memorandum on the use of flash welding has been prepared and has laid the basis for further co-operative work on the subject.

In the investigation on the spot welding of light alloy at the Abington Research Station, good progress has been made in developing methods for measuring all possible variables in the process. This in itself is a major piece of work, and has already yielded interesting information on the performance of the machines. When spot welding proper is carried out, it will be possible to obtain a more comprehensive record of the process than has ever been attempted before and thus reveal clearly the factors which effect the consistency of welding.

Publications

Welding Research, which is issued both separately and as a supplement to the *Transactions of the Institute of Welding*, continues to be the main medium for the open publications of the Association reports. A list of papers appearing in this journal, together with other publications sponsored by the B.W.R.A. is appended.

Reports Published in "Welding Research"

Research Supplement to the Transactions of the Institute of Welding.

Vol. 2, No. 5, October, 1948. "Recommended Practice for Spot Welding of Low Carbon Mild Steel Sheet." "Gas Welds in a High Strength Aluminium-Zinc-Magnesium-Copper Alloy," by J. Pendleton. "Further Investigations on the Pressure Welding of Light Alloy Sheet," by R. F. Tylecote.

Vol. 2, No. 6, December, 1948. "Further Tests on Stanchions," by Professor J. F. Baker and J. W. Roderick. "Investigations into the behaviour of Welded Rigid Frame Structures—Seventh Interim Report."

Vol. 3, No. 1, February, 1949. "The Pressure-Butt Welding of Light Alloy Bar," by R. F. Tylecote. "Short Time Phenomena in the Iron Welding Arc. Metal Bridging and Short Circuiting of the Arc," by L. H. Orton and J. C. Needham.

Vol. 3, No. 2, June, 1949. "Welding as a means of economising on Material and Labour in the Manufacture of Machinery Structures used in General Engineering," by F. Koenisberger. "Welding as applied to Shipbuilding," by L. Redshaw.

Miscellaneous Reports

"Report on a visit to the U.S.A. in May-July, 1948," by H. G. Taylor.

"Trends in American Welding Research and Practice," by H. G. Taylor, Director of Research, B.W.R.A.

" Research at Abington—The B.W.R.A. Engineering Laboratories." (Reprinted from *Welding*, July, 1948).

" A Multi-Point Furnace Control Panel," by C. L. M. Cotterell. (Reprinted from *Metallurgia*, Vol. 38, No. 225, July, 1948).

" Present Position on Residual Stresses in Welded Structures," by R. Weck. (Reprinted from the " Transactions of the Institute of Welding," 1948, 11, 4.).

" Recommended Machine Settings for Resistance Welding in Mass Production," by A. J. Hipperson and T. Watson. (Reprinted from *Welding*, Vol. 16, No. 10, October, 1948).

" Thrusts and Stresses in two dimensional Pipe Expansion Bends," by J. R. Finniecome. (Reprinted from " Proceedings of the Institution of Mechanical Engineers," Vol. 158, 1948).

" Review of Recent Investigations into the Behaviour of Steel Frames in the Plastic Range," by Professor J. F. Baker.

" Welding as an aid to the saving of Steel and Manpower in Railway Workshops," by G. Foster.

" Welding as a means of economising on Material and Labour in the Manufacture of Machinery Structures used in General Engineering," by F. Koenisberg.

" The Economics of Weldings and Castings covering Machine Frames within the range of 5/35 tons," by E. C. Moore.

" Welding as applied to Shipbuilding," by L. Redshaw.

" Welding in General and Constructional Engineering," by W. S. Atkins.

" Welding as applied to Railways and Rolling Stock," by R. C. Byrne.

" Welded Structures," by S. M. Reisser.

" Welding on British Railways—Trackwork and Structures," by N. W. Swinnerton.

" Economy of Steel and Cast Iron by Welding." The Institute of Welding Report.

" Economic Construction of Moderate Sized All-Welded Ships," by H. H. Hagan.

Papers presented to Joint Conference on " Welding as an aid to the saving of steel and Manpower," held at Ashorne Hill, Leamington, March, 1949.

A contribution to the above series by Dr. D. F. Galloway, Director of the Production Engineering Research Association, has been unavoidably delayed and will be published in the next issue ; a summary of the first research report of this Association, however, is included.

Packaging of Engineering Equipment

Report by the Production Engineering Research Association

The first research report of P.E.R.A., issued to member-firms, deals with the above subject. It is significant of the importance of this auxiliary process that a research organisation should investigate and report on it to assist firms to obtain for their products the maximum protection in transit at low cost. The report is summarised.

As many of the engineering firms in Great Britain export large quantities of their products, a review of the available packaging material and methods has been made by P.E.R.A. to assist in improving the quality and economy of packaging, which is now an important auxiliary process of engineering production.

Practical methods of packaging of engineering equipment to-day must in most cases be a compromise between giving the maximum amount of protection and keeping the cost, in time and material, to a minimum. In the recommendations on packaging methods contained in this report an effort has been made to keep the balance between these two factors. The recommendations given in the report are based not only on the conventional methods enumerated in the packaging specifications issued by the B.S.I. and the various Ministries, but also on information concerning conditions prevailing during the transportation of goods to their destination.

Although the report will be primarily of use to personnel concerned with the planning of packaging of engineering equipment, the way in which it is presented is intended to be of immediate assistance to personnel directly engaged on packaging activities in the same way that various handbooks and manuals on production activities, such as tool grinding, machine shop practice, cutting fluids, etc., to be issued by P.E.R.A. in due course will convey summarised information straight to foremen and operators in machine shops and other departments directly concerned on production.

Section I : Causes of Damage and Deterioration of Goods

The causes of damage to goods and packaging materials are classified as (*a*) climatic, and (*b*) mechanical, covering damage caused during loading and unloading, sea or land passage, and in storage. It is often the cumulative effect of climate and maltreatment which causes the damage.

Climatic Causes

Changes in temperature and humidity are the chief causes of damage.

Condensation.—Under certain temperature and pressure conditions humid air in a closed container condenses moisture on to the goods contained. This easily occurs in sealed containers in which insufficient provision is made for controlling humidity content. Increases in humidity inside a container, due to decrease in temperature, are rapid. Methods of preventing condensation are discussed in sections II and III.

Rainfall.—Total annual rainfall and highest monthly average rainfall for each month of the year are tabulated in towns and countries throughout the world. Precautions for preventing ingress of water into packing cases are described in section II.

Growth of Fungus.—Goods transported through tropical countries should be protected from fungus. It is estimated that there are over 100,000 of species in existence, and fungal growth is accelerated by heat, heavy rainfall, and proximity of the jungle. Soft materials, such as leather, canvas and cloth disintegrate when fungus grows on them, and may be rendered completely useless after a few days.

Termites.—These insects, which eat dead wood, occur chiefly in tropical areas.

Mechanical Causes

When containers are subjected to excessive blows or forces, they may yield or break, exposing the goods. The ways in which damage may occur from various

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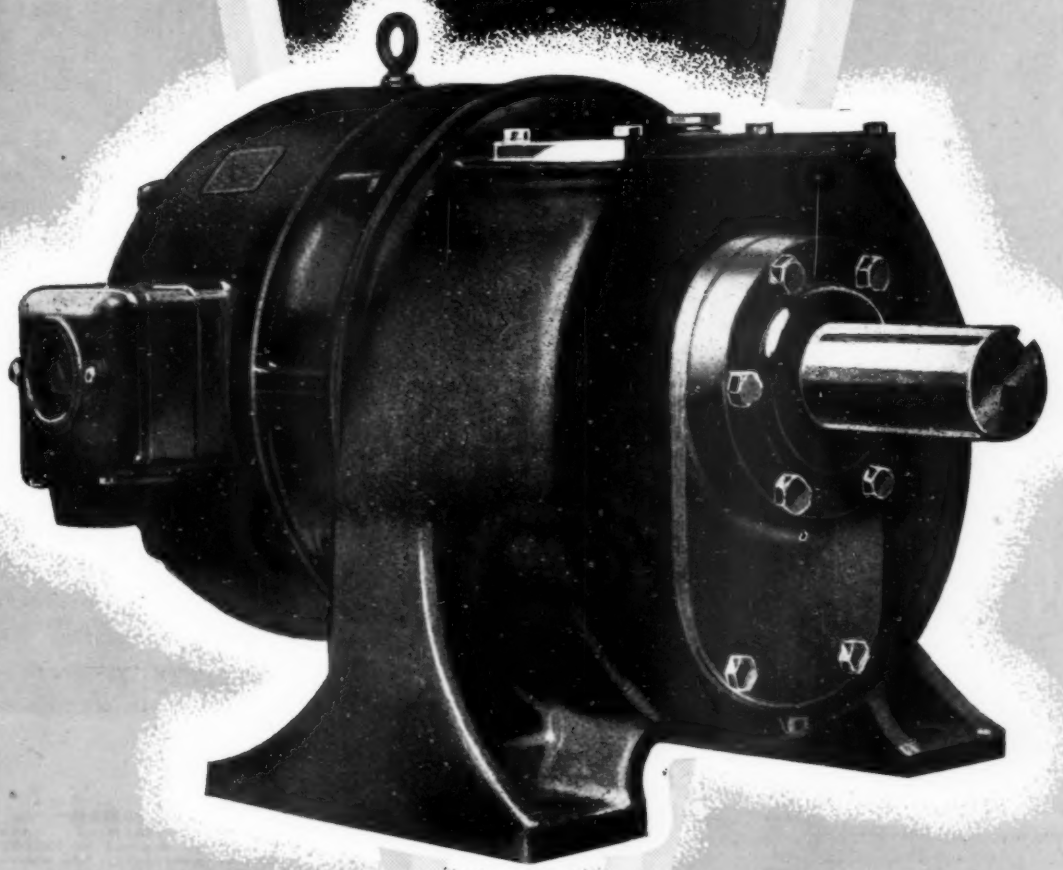

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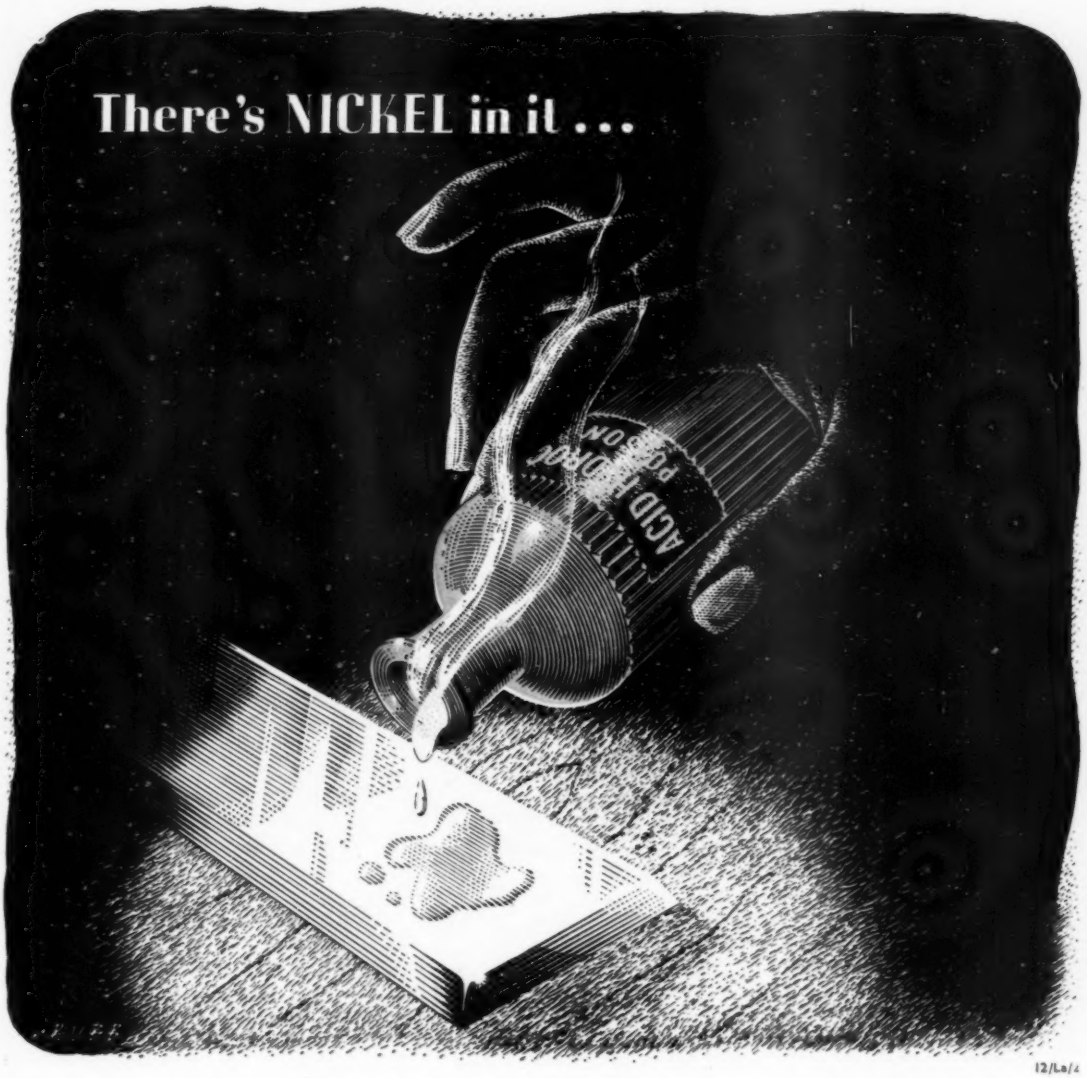

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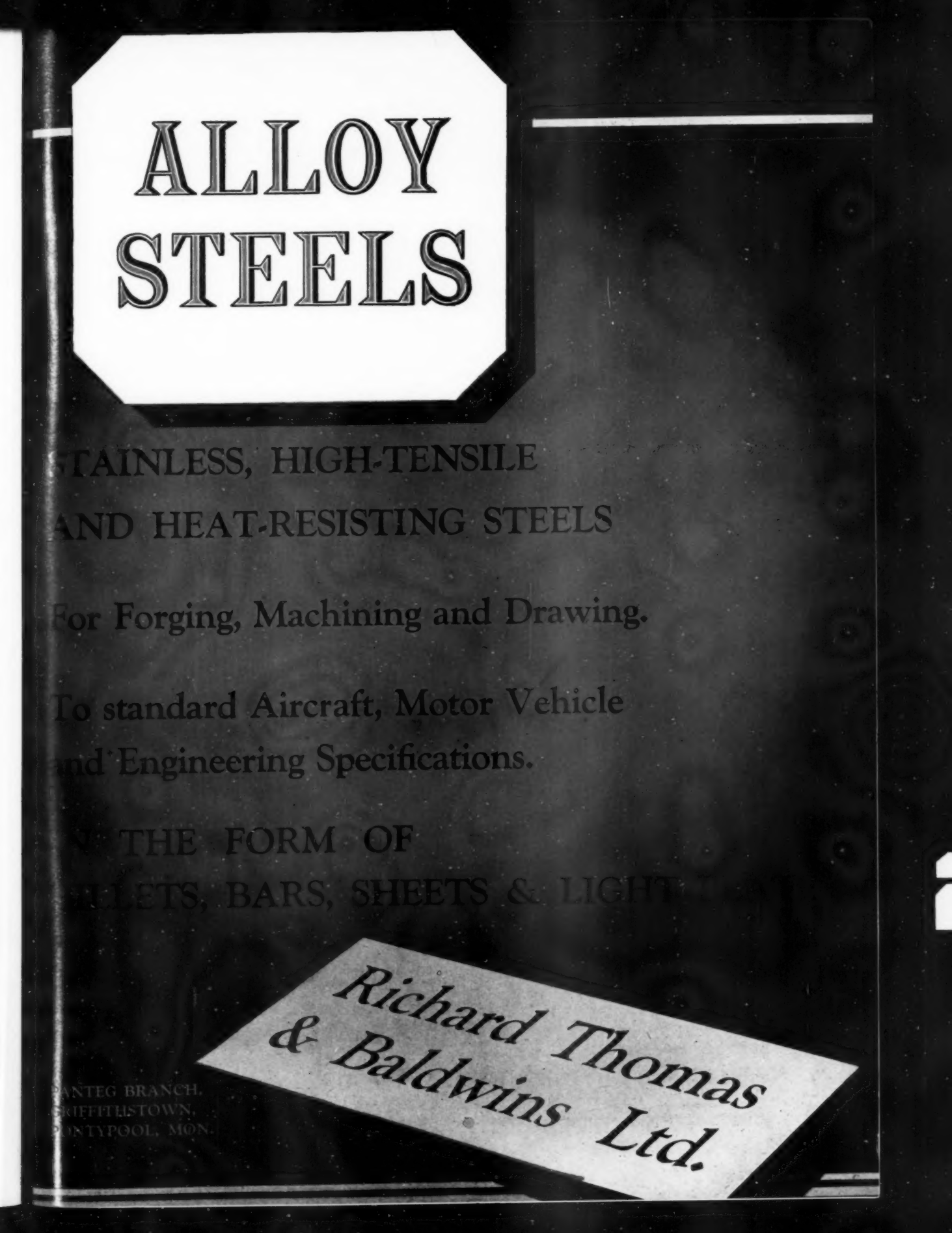
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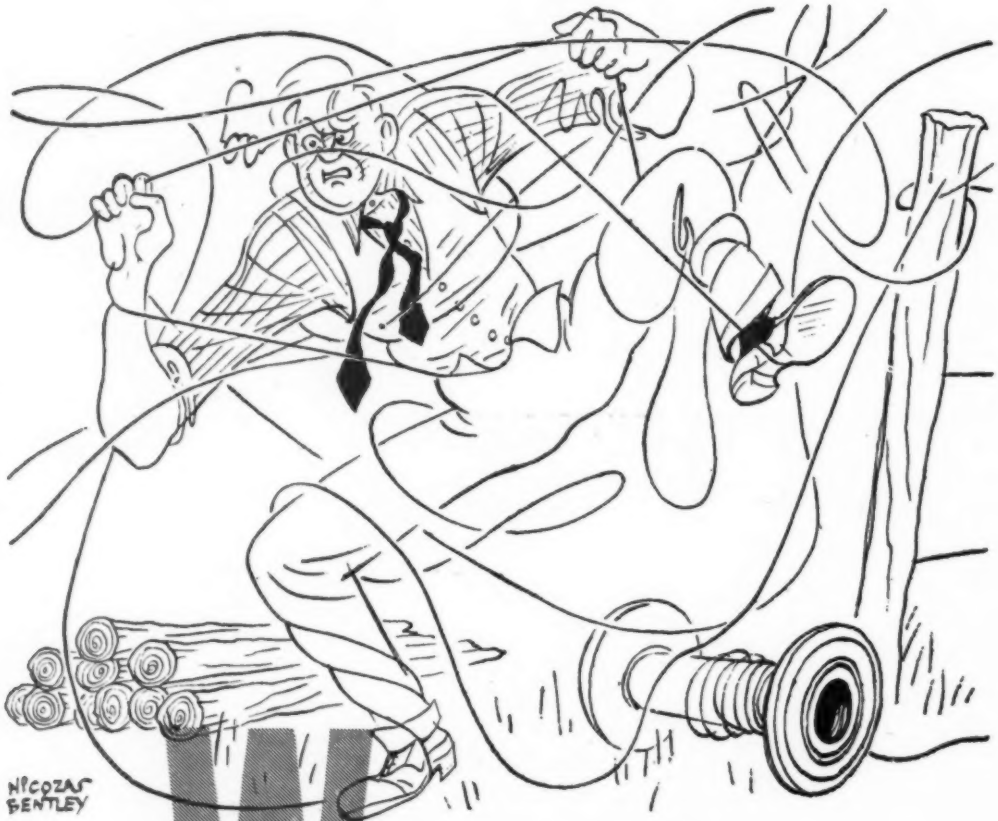

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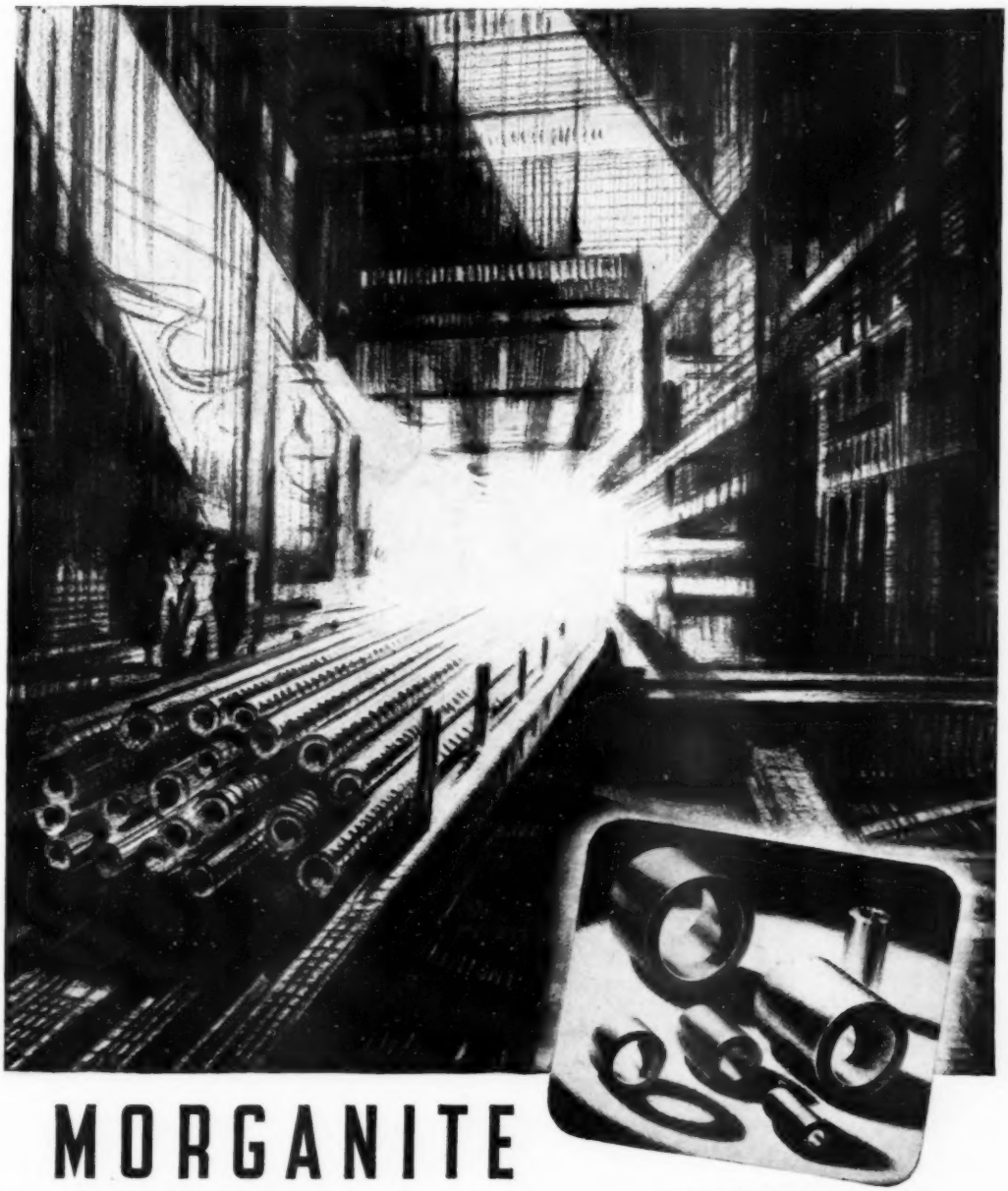

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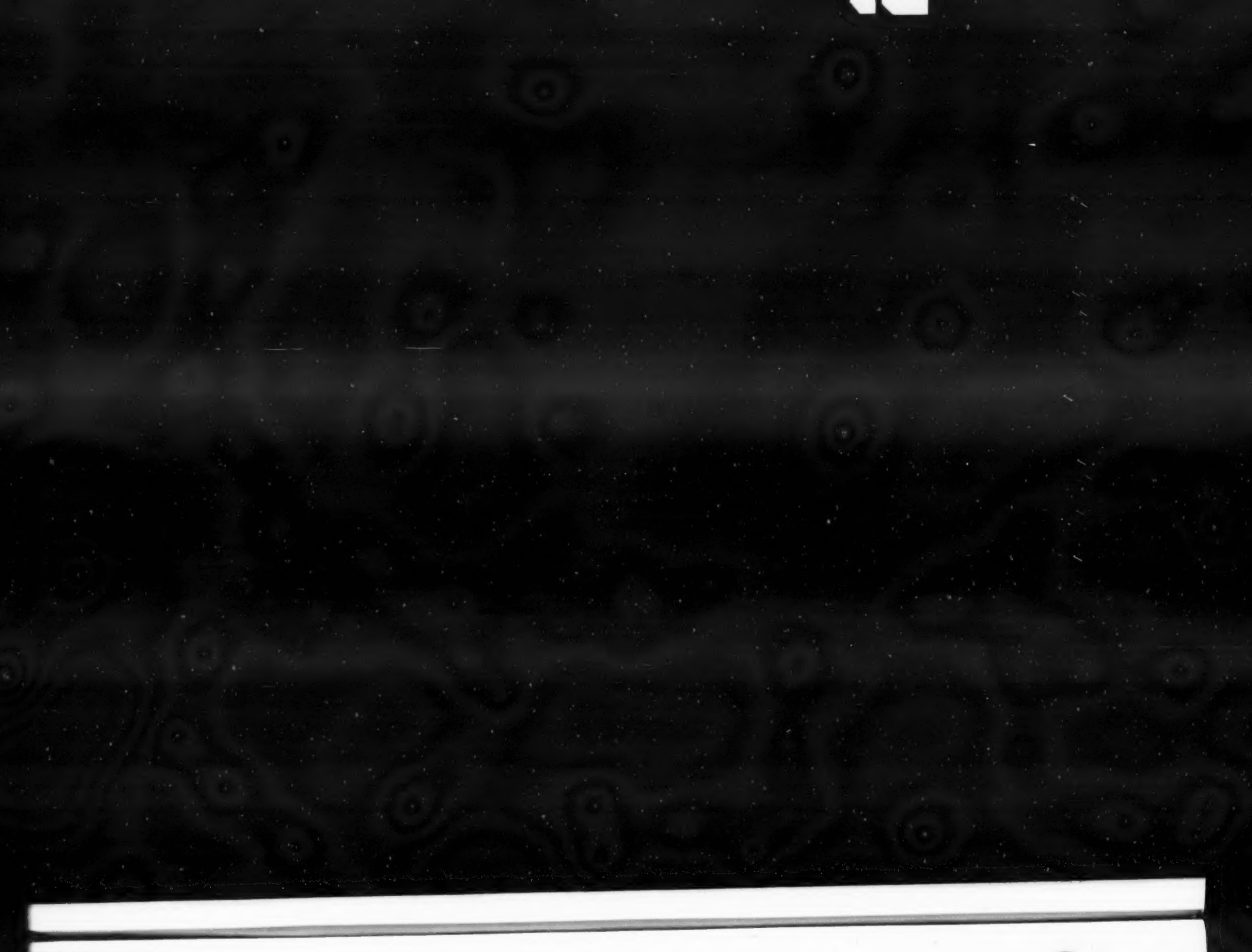

Progress in Optical Methods

Conference at Ashorne Hill

Metallurgical applications of new optical developments have long lagged behind those in the field of biology. That this is so is illustrated by the fact that of three techniques discussed at the Ashorne Hill Conference, arranged by the Optical Methods Sub-Committee of B.I.S.R.A.'s New Techniques Committee, two are still in their infancy as regards metallurgical work, although considerable experience has been gained in biology. The existence of such a Committee should do much to rectify the position and the holding of such conferences should enable the optical experts to appreciate the needs of the metallurgist.

SHORTLY after the end of the War, the British Iron and Steel Research Association set up a New Techniques Committee to study and initiate experimental work on techniques and methods which had not previously been applied in the steel industry. It was soon evident that the field was so wide that division into a number of sub-committees was essential to the carrying out of the allotted task. One of the sections so-formed, the Optical Methods Sub-Committee, has this year held a conference to discuss certain aspects of its work, under the Chairmanship of Dr. G. K. T. Conn, Chairman of the Sub-Committee. Some idea of the interest aroused can be gauged from the large attendance—some 150 drawn from the steel industry, engineering, the non-ferrous industry and the universities.

In opening the Conference, Mr. E. W. Colbeck, Chairman of the New Techniques Committee, said that it had been necessary to explore, in a preliminary way, a large number of different ideas, some of which had then been considered as incapable of application in the industry. Others had required further work to develop them to the stage at which they could be used, such work being carried out under the supervision of the Committee.

In his introductory remarks Dr. Conn said that although the three topics selected for discussion—phase-contrast microscopy, the reflecting microscope, and multiple beam interferometry—were rather diverse, they had been chosen quite deliberately. Phase-contrast microscopy had been available for some considerable time and had been used fairly extensively in biological fields, but did not seem, until recently, particularly at the National Physical Laboratory, to have been used in the field of metallurgy. It was felt that it had a certain application in this field. Although not entirely a new invention, the reflecting microscope, largely through the work of Dr. Burch, had been altered quite dramatically in the last few years, making it a practical working tool. It had two advantages: (1) an appreciably greater working distance than the ordinary microscope which, for metallurgical applications, particularly at high temperatures, should be of real value, and (2) it was achromatic, i.e., once it was set up and focused for one particular wavelength it could be used and applied for any wavelength without readjusting the focusing. Multiple beam interferometry on the other hand was still very much in the realm of academic research. It had, however, recently been applied to metallurgical problems and it was felt there was a large number of problems to which it could be applied.

Phase-Contrast Microscopy

Principles

Mr. K. J. Habell, of the National Physical Laboratory, where considerable work has been carried out on the subject during the last few years, dealt with the principles on which the phase-contrast microscope has been developed.

Light reflected from various areas of the surface of a metal specimen may differ in intensity, i.e., in amplitude, in which case the ordinary microscope will enable the difference to be observed. On the other hand phase-differences may be introduced, either by differences in level or by differences in the surface material but, unless the phase differences are accompanied by intensity differences, they will be invisible in the ordinary microscope as the eye is not sensitive to differences in phase. The phase-contrast microscope has been developed to render the phase-differences visible by changing them into intensity differences.

In the image formation of macroscopic objects, for most purposes a satisfactory estimation of the size and position of the image can be made by the use of the general principles of geometric optics. The light incident on the object can be considered as either intercepted or transmitted with appropriate modulation of intensity. With microscopic structure, however, such a consideration is insufficient, and to determine that light distribution which constitutes the image the behaviour of light diffracted by the object must be taken into account; in fact it is this diffracted light which is representative of the character of the object.

Considering two grating objects illuminated by transmitted light, one an amplitude grating consisting of finely-spaced opaque and transparent bands, and the other a phase grating consisting of a series of small parallel depressions in a glass surface, each will allow most of the parallel beam of light to be transmitted directly, but varying amounts will be diffracted at different angles; the angle and intensity of the diffracted beam depending on the nature of the object structure. The directly transmitted light, and as much of the diffracted light as enters the objective, is refracted by the latter to the image plane, where the beams superimpose to give a light distribution which may resemble that of the object, the closeness of the similarity being dependent on how much of the diffracted light is collected by the objective. As the light proceeds to the image plane, distinct concentrations are formed in the rear focal plane of the objective; in fact in this plane are formed images of the light source. These diffraction images

may be seen on viewing the back of the objective with the eyepiece removed. For recognisable variations in intensity in the image, at least the first diffraction maxima on either side of the direct beam must be collected by the objective. The amplitude grating will thus appear in the image plane as alternating light and dark bands but the phase grating image will be of uniform intensity.

Zernicke showed that an essential difference exists between the diffraction maxima formed by amplitude and phase gratings. When the phase variations are small, the diffraction maxima differ in phase from those of the corresponding amplitude grating by $\lambda/4$. If the maxima can be retarded in phase (relative to that of the direct beam) by $\lambda/4$, the diffraction pattern will be identical with that of an equivalent amplitude grating and corresponding variations in intensity will be observed in the image plane. Elements of the object which produce a small retardation of the transmitted light will appear as dark areas on a brighter background. This is termed positive phase contrast : in negative phase contrast the phase of the maxima is advanced by $\lambda/4$ and the light and dark regions are reversed.

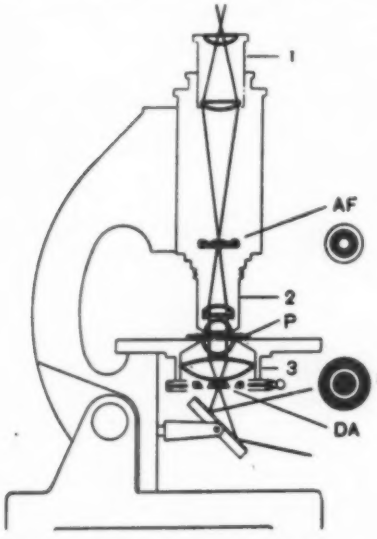

Fig. 1.—Section of Galileo phase-contrast microscope for use with transmitted light

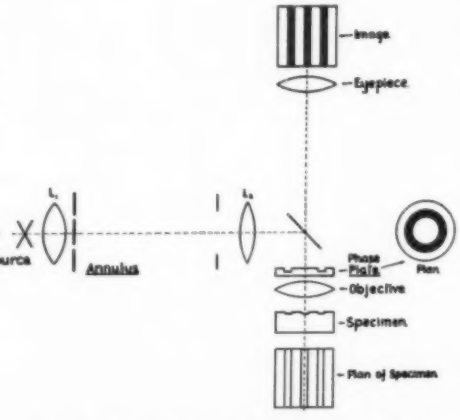

Fig. 2.—Optical arrangement of the phase-contrast, incident-light microscope.

In general, objects will not consist of ideal phase gratings, but fine structures differing in optical path by small amounts, whether transparent or opaque (such as metals), will act in the same way. As the intensity of the direct beam is much greater than even the first order diffraction maximum, the contrast can be increased by reducing the intensity of the direct beam relative to that of the diffracted beams. In the phase-contrast microscope the phase of the diffracted light is altered by $\lambda/4$ relative to the direct beam and the intensity of the latter is suitably reduced by the insertion, in or near the rear focal plane of the objective, of a phase plate whose shape depends on the effective light source which is imaged there.

A typical optical arrangement is that employed in the Galileo phase-contrast microscope shown in Fig. 1, while the arrangement of the metallurgical phase-contrast microscope, or what has been called the phase-contrast, incident light microscope, is shown in Fig. 2. The light source is imaged by a condenser lens L_1 into the plane of the iris diaphragm close to a second condenser lens L_2 : the latter together with the microscope objective images the source in the plane of the specimen, the light being turned through 90° by a semi-transparent reflector. The annular diaphragm close to L_1 is imaged by condenser lens L_2 in the plane of the phase plate, mounted in or near to the rear focal plane of the objective. With this arrangement, light specularly reflected by the reflecting surface of the objective is returned to re-image the annular diaphragm in the same plane : the specimen is adjusted in the incident light beam so that the annular image is centred with respect to the phase plate.

The phase plate itself has a corresponding annular deposit of a substance such as magnesium fluoride, of such a thickness that light passing through has its phase retarded by $3\lambda/4$. In this way specularly reflected light passes through the deposit, whereas the diffracted light does not, and is, therefore, retarded by $\lambda/4$ relative to the direct light. A semi-opaque material is included in the deposit to reduce the intensity of the direct beam.

For the operation of phase-contrast, the specimen must be sufficiently well polished for the light incident on it to be specularly reflected, and thus to be re-imaged by the objective coincident with the annulus of the phase plate. If the surface is so rough that the incident light is diffusely reflected, phase-contrast cannot operate. With a phase plate producing a phase change of $\lambda/4$, fine structure with a depth of the order of $\lambda/20$ is seen in good contrast. For coarser structures, the gain in visibility is less and for steps of about $\lambda/8$ the improvement is barely appreciable.

In conclusion, Mr. Habell pointed out that the method would not replace existing metallographic techniques, rather should it be regarded as complementary to them.

Metallographic Applications

Although certain microscope firms had previosuly built and experimented with a reflection type phase-contrast microscope, it is probable that the first metallurgical laboratory to operate one was the Metallurgy Division of the National Physical Laboratory, where F. W. Cuckow set one up in 1947. So far it has only been possible to explore the potentialities with a high power oil immersion lens but it is unlikely that the use of lower power lenses will alter any of the general conclusions, arrived at as a result of two years' experience at the N.P.L., which Mr. D. McLean illustrated by lantern slides of photo-micrographs taken by phase-contrast and normal techniques.

A striking illustration (Figs. 3 and 4) of the way in which differences in level in non-contrasting areas are shown up was given by the appearance, in the phase-

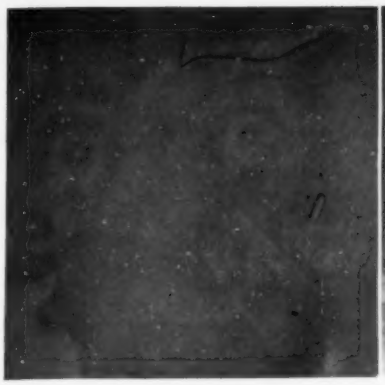

Fig. 3.—Slip lines in the alpha phase of lightly deformed alpha-beta brass as seen under the normal microscope.

Fig. 4.—The same field seen under the phase-contrast microscope where differences in level are seen in contrast. ×1500

contrast microscope, of slip lines in brass. In this case the level differences were about $\lambda/10$ or 500Å and no edge effect was apparent, although later slides showed that for much bigger vertical displacements there is a pronounced edge effect. It is probably a conservative estimate to say that level changes of 50Å can be detected and it need hardly be pointed out that the instrument is therefore a remarkable detector of scratches and other unwanted imperfections. (See also Figs. 5 & 6).

Bigger level changes, such as those of about $\lambda/2$ between the matrix and the hard particles in a bearing metal, do not produce phase-contrast between matrix and particles although it is obtained within each. There is an intense white fringe round the hard particles, presumably because the particle sides pass through the level for maximum brightness.

Relatively heavy etching, applied to the brass showing slip, illustrated the way in which roughening of the surface obliterates the phase-contrast effect.

A fairly uniform phase-contrast effect is obtained over large areas differing in level, as well as over small areas, as was shown by a field containing little more than two ferrite crystals with a few small carbide particles.

The behaviour of small particles is of considerable interest is phase-contrast microscopy. The small carbide particles referred to above, which are known to stand proud, appear bright under phase-contrast illumination.

Examination shows that, for such particles, the resolution is about the same as with normal illumination but, for depressions below the surface level, such as pits or cementite in a ferrite matrix after electrolytic etching with chromic acid, the phase-contrast illumination definitely gives better effective resolution—a term which doubtless includes visibility. (These observations refer to positive phase-contrast). It is not always possible to tell with certainty whether a particular feature is a depression or an elevation. Small elevated particles are apt to appear dark and, if level differences are too great, the phase relations cease to be an unambiguous guide. Moreover, black inclusions appear white under phase-contrast illumination, thus vindicating theory. However, with experience, and especially if occasional comparison with the electron microscope can be made, it is usually possible to be fairly certain.

Finally Mr. McLean referred to the manipulation of the phase-contrast microscope. As it stands at present, it is a little more troublesome to use because of the extra adjustments that have to be made. The adjustment required with commercial instruments becomes quick and simple, after a little practice, though it can be confusing on first acquaintance. It is hoped that this will not hinder the widespread adoption of the phase-contrast technique.

Fig. 5

Fig. 6

Fig. 5—Solution-treated and quenched magnesium alloy containing 1·5% manganese seen under the normal microscope.

Fig. 6.—The same field seen under the phase-contrast microscope. Note the increased contrast in the twin structure. The small black dots, corresponding to the faint particles in Fig. 5, are as prominent as the bright spots which correspond to the black dots there. ×1500

Discussion

Several interesting points were raised in the discussion which followed the presentation of the papers. On the question of difficulties in interpretation, both speakers agreed that, whilst it was perhaps a little more difficult than with the normal microscope, experience soon taught one to pick out the true from the false.

Dr. A. F. Hallimond of the Geological Survey discussed and demonstrated a simple arrangement which gave what he termed "stop contrast." A stop is used to cut out the direct beam so that regions slightly inclined to the normal are thrown into marked relief. The arrangement is therefore of particular value in examining grains with a small tilt.

On a practical issue Mr. E. W. Taylor said that his firm had

altered the position of the phase plate so that the glass slip reflector for vertical illumination of an opaque object, e.g. metal, could be inserted between the phase plate and the objective, with a view to preventing reflection of incident light from the phase plate.

In comparing positive and negative phase-contrast, it was suggested that the latter would result in improved resolution of the slightly raised portions as compared with the normal microscope.

Dr. C. R. Burch raised a very interesting point when he suggested that the use of a partly-absorbing—but not phase-changing—annulus, to reduce the intensity of the direct image, would result in enhanced contrast in the diffracted images. Of course this would be of no value where phase-contrast was required, but it would give contrast enhancement of grey-white detail, the detailed contrast of which was normally too weak to be seen. It appeared that the method had not been tried, although similar work was in progress for biological purposes.

In view of the phase retardation being specified as $\lambda/4$ the impression was gained that monochromatic light was necessary but Mr. McLean said that whilst an ordinary photographic filter was used for the sake of the lens focusing conditions, the phase-contrast effect did not demand it. From their experience he would say that phase-contrast was not so critical a system as the literature might lead one to expect.

The Reflecting Microscope

As the result of the efforts of Dr. C. R. Burch and his co-workers at Bristol University, the reflecting microscope is now an actuality, although the supply position is still by no means good. Papers on this subject were given by two members of the Bristol School—Mr. R. L. Drew, who dealt with principles, and Mr. K. W. Keohane, who described some metallurgical applications.

Principles

Perhaps the earliest attempt in this field was that of Newton, who employed an ellipsoidal mirror working between the two foci, at which points there is freedom from spherical aberration. The outstanding drawback is the different zonal magnification, or coma, as the aperture is increased. On the other hand, due to the wave nature of light, a point is imaged in a diffraction pattern which, to be small, necessitates the use of a wide aperture. It was not until some 200 years later that Abbe clarified the problem of imaging and pointed out the necessary sine relationship between the angles diverging from the object and converging to an ideal image point, for freedom from coma. For this it is necessary to use at least two mirrors.

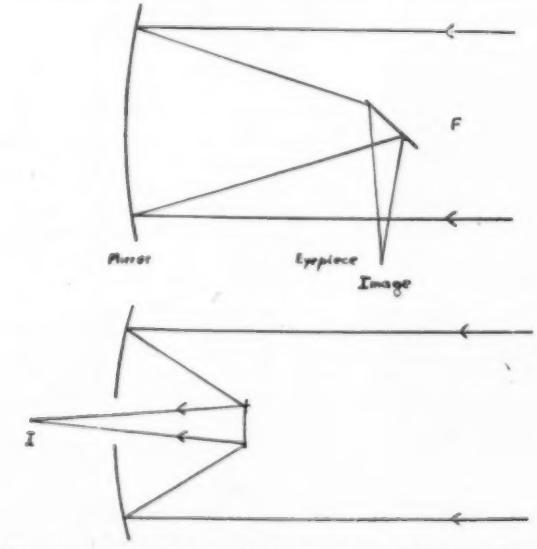

Fig. 7.—Two ways of setting up a reflecting telescope. Upper—the Newtonian set-up. Lower—the Cassegranian set-up.

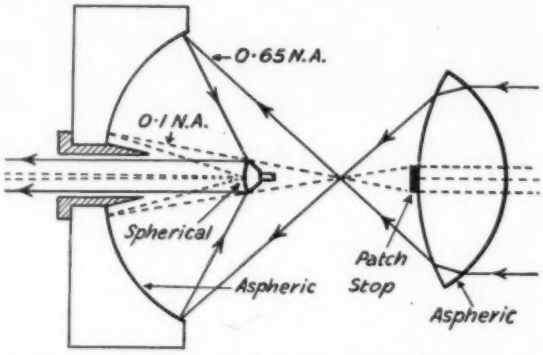

Fig. 8.—The set-up of a reflecting microscope for use in transmission work. Ideally a reflecting condenser should be used, but for most purposes a refracting one is suitable.

In 1905 Swarzchild solved the general problem of a two-mirror system, free from spherical aberration and fulfilling the sine condition, the solution of his differential equations giving the shape required (generally non-spherical) to obtain these aplanatic pairs—used telescopically. This was confirmed in 1922 by Chretien, who independently obtained Swarzchild's results from an analysis instigated by Ritchey, who had noticed improvements in performance of the Mount Wilson telescope when used as a Cassegranian instrument as against a Newtonian set-up.

About 1934 Dr. Burch's interest led him to consider the possibility of making a microscope using reflecting surfaces only, and the Swarzchild analysis, being equally applicable to microscopes, became a starting point for present models. The analysis contained a whole series of microscopes and Burch chose one which had a slight amount of asphericity—a matter of ten fringes or so—and finally completed it with a slight amount of asphericity on both mirrors.

Further examination of the Swarzchild analysis showed that it is possible to make a microscope with both mirrors spherical up to a numerical aperture of 0·5. There are limitations to such an instrument: it is necessary to have half the light from the object stopped out by the small mirror and that affects the resolving power and can lead to possible upsets in contrast. To get rid of these effects it is necessary to reduce the obstruction ratio to the order of one-sixth or one-seventh. In this case one mirror can be spherical, e.g., the smaller one up to N.A. 0·65, it being preferable to aspherise the larger mirror both from a constructional point of view and also because it results in a lower astigmatic coefficient. Burch constructed manually an instrument of N.A. 0·65, in this way, with a working distance of 14 mm. in air and 5mm. with an oil component. (Fig. 8).

Most of the slides shown were drawn from the biological field in which the reflecting microscope has been most extensively tried.

Advances in aspherising techniques, involving the use of a cam-controlled floating polisher, are making manually easier the constructional problem and have brought nearer the advent of instruments with a higher numerical aperture, flatter fields and so on.

Metallurgical Applications

Of necessity little work has been done on metallurgical applications of the reflecting microscope, as a fairly substantial grant was received from the Nuffield Organisation some two years ago to provide microscopes which were in the first place to be developed for medical purposes. Nevertheless, it was felt that something should also be done on the metallurgical side and although they were only at the beginning of the work, they had shown, as had been demonstrated at the Conference, that the 0·65 N.A. microscope can be used for normal metallurgical work at the cold stage. It gives equivalent resolution to the normal type with 4 mm. working distance, but has a working distance of 14 mm. The maximum resolution obtained is simply a property of the numerical aperture. Magnifications of roughly 1,000 N.A. are usual with microscope objectives, and that applies equally to the reflecting type, so that magnifications of the order of x750 can be obtained with the 0·65 N.A. instrument on show.

Fig.9—Photo-micrograph of oxide coatings produced by heating molybdenum—taken at temperature with the reflecting microscope.

The two main points about the instrument are its long working distance, which is likely to be of immense value to metallurgists in high temperature microscopy, and that it is completely achromatic, which enables the instrument to be focused in a convenient region of the spectrum, and then used on any other wavelength, from infra-red to ultra-violet, without re-focusing. In the far ultra-violet (2,000 Å region) the resolution is more than doubled, so that the useful magnification goes up to the region of x1,700 with 0·65 N.A.

So far, work on the usefulness of the long working distance in high temperature microscopy has been confined to a demonstration that the image does not lose definition as a result of the hot specimen being so close to the objective. Pictures of oxide coatings on molybdenum were obtained up to white heat, without loss of definition, as was illustrated by a series of photomicrographs at increasing temperatures. (Fig. 9).

Dutch Reflecting Microscope

One of the main difficulties in the production or reflecting microscopes is the preparation of the aspherical surfaces. Dr. Ir. F. Hekker described a comparatively cheap instrument developed in Holland, in which only spherical surfaces are used.

A single spherical concave mirror has three important advantages over a single positive lens: (1) perfect achromatism; (2) the spherical aberration amounts to only $\frac{1}{8}$ as compared with a single lens of equal focal length and diameter; and (3) if a diaphragm is located at the centre of curvature of the spherical mirror, the image is fully free from astigmatism and coma. Thus the spherical concave mirror with a diaphragm at its centre of curvature has only two aberrations left, i.e., a small spherical aberration and pure curvature of field. The latter can be "corrected" by using a curved image, which has appeared to be quite feasible for many applications, whereas in the Oude Delft mirror-microscope the curvature of field of the mirror is even very welcome. In fact it compensates for the curvature of a normal eyepiece. In order to correct for the spherical aberration, a correcting element of appropriate shape and dimensions has to be added to the mirror. A well-known type of this element is the Schmidt-plate, which is widely used for astronomical purposes. However, it has an aspherical surface and therefore it is difficult and expensive to make. Moreover the plate introduces coma and astigmatism so that the field of view is limited to 20° at the most.

Bouwers has invented another type of correcting element, a meniscus lens with spherical surfaces. If these surfaces are concentric with each other and the mirror-surface, the freedom from astigmatism and coma is maintained. The small chromatic aberration due to the meniscus can easily be dealt with. This mirror

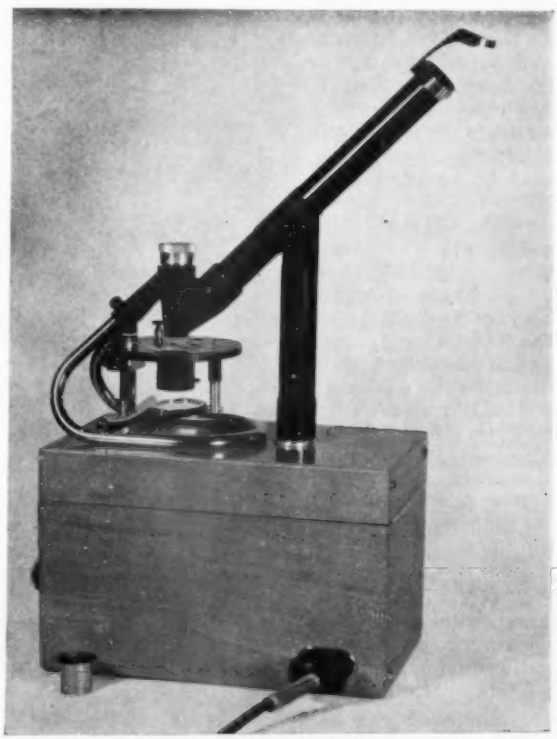

Fig. 10.—The Oude Delft, Reflecting Microscope Model O.D. 200.

meniscus system has proved to be very successful as it yields wide-angle images of great luminosity, though it contains only three optical surfaces.

One of the many applications is the mirror microscope O.D. 200 with N.A. 0·20, which is available commercially. (Fig. 10). Apart from the typical optical characteristics of the mirror system, i.e., perfect image-definition in a large field, the following practical properties of the instrument as actually produced, may be mentioned here : (1) the box in which the microscope can be transported contains an illumination device for the use of the microscope as projector. The image can be projected either on the table or on a screen ; (2) micro-photographs can be made directly without a camera, by putting photographic material on the table in a dark room ; (3) the microscope can be used for both transparent and opaque objects ; (4) internal focusing so that there is a fixed object distance of 8 mm. ; (5) the oblique tube makes observation through the eye-piece comparatively convenient. The instrument is very flexible and it has proved to be successful in many fields of research, including metallurgy, biology, examination of textiles, etc.

Mr. W. E. Seeds then described a reflecting microscope with a numerical aperture of 0·5, in which only spherical mirrors were used. It has been found in practice that it is possible to take any two mirrors, the ratio of whose radii lies between 1/2·5 and 1/3·5 and construct, at a cost of some £50, a microscope of reasonable performance provided the positions of the mirrors can be accurately adjusted on an interferometer or similar arrangement. The essential feature of the instrument is that the small mirror must be mounted on a system of fine adjustments. With this system it has been found that the optimum reflector obtainable has a numerical aperture of 0·6, a focal length of 5mm. and a clear working distance, from the back of the small mirror mounting, of 9 mm. The objective will fit on a normal microscope and at the normal tube length will give a x36 primary magnification. It can also be readily adapted for phase-contrast work. The instrument is not ideal and the contrast is probably low, but for most of the work for which a reflecting microscope is required, this form of objective has a real place.

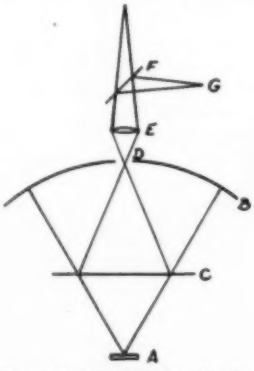

Fig. 11.—Principle of high temperature microscope.

The last optical system to be described was that of the high temperature microscope being developed by B.I.S.R.A. The system is similar to that devised by Dyson*. The basic principle in each case is as shown in Fig. (11) ; A is a transparent specimen, illuminated from below and placed at the centre of curvature of a concave spherical mirror B. A half silvered plane surface placed at C causes a real image of A to be formed at D. This real image is the same size as the original object and may be observed through an aperture in the concave mirror

*Dyson, J. : " A Unit Magnification Optical System with Long Working Distances for Microscopical Applications," *Nature*, 1949, **163**. 400.

The system is well adapted for the observation of specimens in a heated furnace where the optical components must necessarily be situated some distance from the specimen.

In a high temperature microscope employing an evacuated furnace, the vacuum window may be so thick as to introduce appreciably spherical aberration, and, in the system described by Dyson, shown in Fig. (12), the half silvered surface is formed on the plane face of a glass plate, which itself, owing to its finite thickness, is a source of further spherical aberration ; however, the system is rendered free from spherical aberration by working the unsilvered face of the plate, which is the face nearer the object, to a weak convex curvature.

The version of the instrument developed by B.I.S.R.A. and described by Mr. H. T. Heal is shown in Fig. (13). The concave mirror and the plane half silvered surface are formed on the same block of glass, and another block of glass is cemented to this, having a concave spherical surface concentric with the concave mirror, so that light from the object is incident normally on this surface, and passes through it undeviated. The real image D is formed

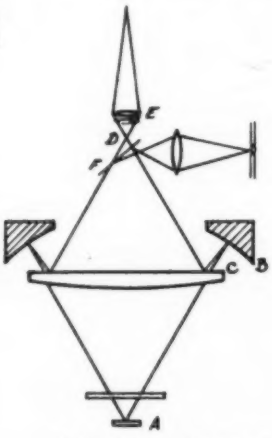

Fig. 12.—Dyson's arrangement.

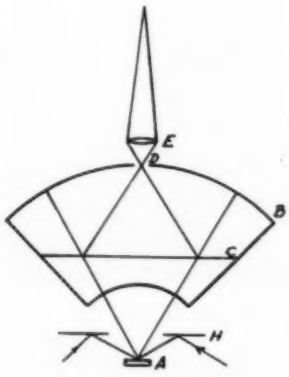

Fig. 13.—B.I.S.R.A. arrangement.

in the neighbourhood of the surface of the glass block which is unsilvered at this point, and this image is observed through an oil immersion objective at E. This system is free from spherical aberration. A mica vacuum window is used, about 0·001 in. thick, and the small amount of spherical aberration introduced by this can be removed by slightly displacing the specimen axially from its normal position at the centre of curvature of the concave mirror and refocusing the microscope.

In applying the system to metallurgical specimens Mr. Heal referred to Fig. (11) in which F represents the pellicle mirror of a normal type of vertical illuminator and G is a light source, and stated that it was uesless because an image of the source will be formed by two reflections at the half silvered plane and one at the concave mirror ; this image coincides with and will obscure the real image of the specimen at D. Dyson overcomes this trouble by placing the pellicle mirror as shown in Fig. (12) and arranging that the image of the light source is displaced axially about 3 mm. along the axis away from the image of the specimen.

In the system proposed by B.I.S.R.A. and shown in Fig. (13), a stop H, subtending an angle of 90° at the

specimen, is placed as shown, its lower face having a plane reflecting surface. Light may be reflected from this surface to produce oblique illumination of the specimen. A possible drawback is that due to the unorthodox methods of illumination necessitated; it may not be possible to employ phase-contrast with the instrument. It is noteworthy that this instrument has been designed and the optical components are being manufactured and results available from it will be reported at an early date.

Discussion

In the ensuing discussion the question of the permanence of the reflecting surfaces in laboratory atmospheres was raised. Mostly they are aluminised surfaces and atmospheric oxidation forms a protection. They can be cleaned in a degreaser many times without detriment and gentle rubbing every three months seems to be quite effective although a warning was issued against rubbing in the first three months, whilst the protective oxide film is forming. Protection by a thin layer of quartz was also mentioned.

The relatively low reflectivity of most metals in the ultra-violet range was mentioned by Mr. J. D. Hannah, but it was pointed out that it is still about 60% for aluminium. Professor Tolansky referred to the applications of multiple layers of high- and low-reflecting film, by which it is possible to increase reflectivity to any figure desired, and to the cold mirror which will reflect light but not heat. The latter consists of a thin film of germanium with "sandwich" applied until the reflectivity is raised to about 90%.

Dr. A. Taylor in referring to the hot stage asked about the effect on the resolution of changes in the refractive index of the air between the specimen and mirror, but Mr. Keohane said they had found good definition with hot molybdenum.

Mr. McLean drew attention to a further advantage of the long working distance in the examination of fractures, where it enabled one to tilt the surface until a small portion was parallel to the objective without fouling the latter.

A lively and somewhat inconclusive discussion took place on the subject of useful magnifications with the optical experts taking the view that the numerical aperture is the governing factor and that magnifications of about 1,500 are the maximum obtainable and the metallographers maintaining that one could see detail at x4,000 that could not be seen quite so well at x2,000.

Multiple Beam Interfermetry Principles

The development of the multiple beam technique in interferometry owes much to Professor S. Tolansky, who briefly outlined the subject.

The use of interference methods for examining the topography of surfaces has long been practised in workshops, the method generally adopted being that due to Fizeau in which a parallel beam of light, from a point source and a lens, illuminates the object on which is placed an optical flat. The result is a set of interference fringes, with equally wide light and dark spaces, which contour the surface. If, instead of two beams, a large number of beams are used, then extremely sharp fringes are produced on which accurate measurements can be made. For this purpose parallel light from a point source is needed and the essential condition is that the optical separation between the surfaces must be very small—of the order of a few light waves. The surfaces must also have high reflectivity which is obtained by vacuum deposition of the correct kind of silver film on the surface. The silver film does contour the surface provided the extension is not too great (at magnifications of x300–x400) and provided that the units observed are not less than 1/300 mm. in extension. Many optical systems are in use but only two were referred to by Professor Tolansky, one using monochromatic light and the other using white light which results in the formation of fringes of equal chromatic order.

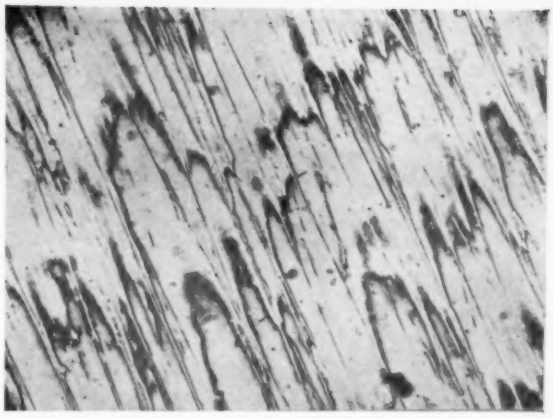

Fig. 14.—Multiple-beam interference fringes on sheet steel for tinplate manufacture.

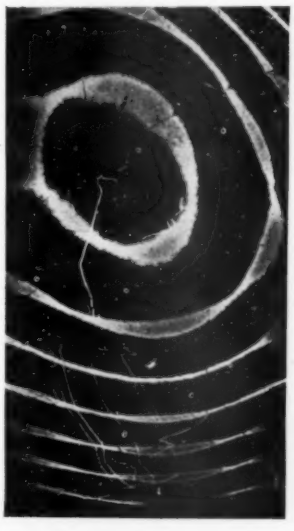

Fig. 15.—Multiple-beam interference fringes photographed during high frequency oscillation of a quartz crystal. Note the thickening of certain sections of the fringes due to oscillation.

Professor Tolansky showed a number of lantern slides to illustrate his remarks. In one of these it was quite clear that with fringes separated by half a wavelength irregularities of the order of 25Å can be measured and, with conditions entirely favourable, even variations of 3Å can be detected. Among the slides of metallurgical interest were those showing the fringes produced on an arcing pit in a piece of tungsten; sheet steel for tinplate manufacture (Fig. 14); alpha-brass showing slip; a diamond hardness impression; and polished aluminium, the latter with fringes of equal chromatic order. (Figs. 16, 17 and 18). A particularly interesting slide showed that slip had occurred in a specimen of aluminium which had been loaded in tension to a stress as low as $\frac{1}{4}$ kg./mm.^{2}. Incidentally the shape of the fringes suggested that rotation had occurred during slip.

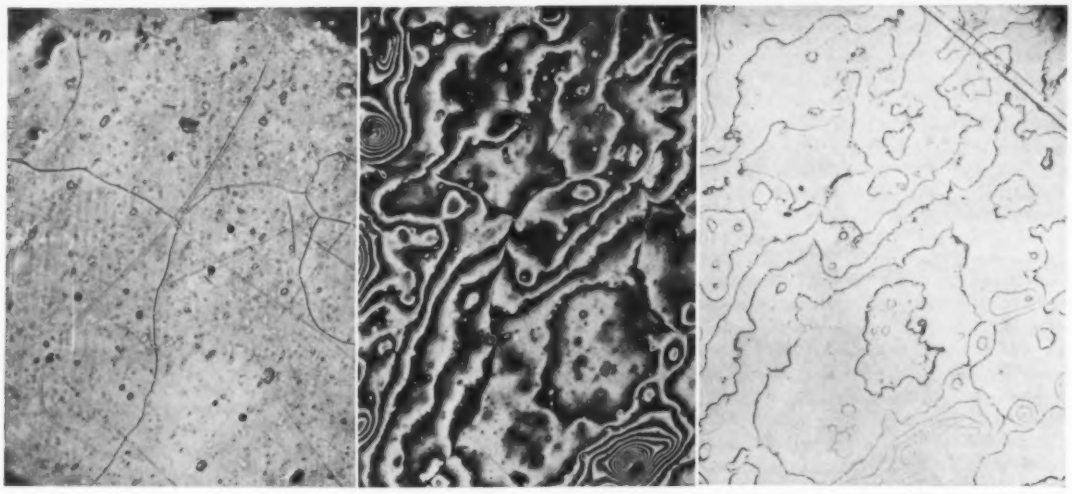

Fig. 16 Fig. 17 Fig. 18

Fig. 16.—Photo-micrograph of etched aluminium showing surface imperfections. ×250

Fig. 17.—The same field with a piece of glass, silvered to about 25% placed on the specimen. ×250

Fig. 18.—The same field with an 80% silvered glass. Sharp fringes are developed and it will be noted that sharp vees indicate the positions where the fringes cross the grain boundaries. ×250

Undoubtedly the most striking slides concerned experiments in which quartz crystals were studied whilst vibrating at frequencies of 100,000 to 3,000,000 per sec. The fringes obtained by placing a silvered optical flat on the silvered quartz crystal formed a stable picture in spite of the oscillation (Fig. 15). By cementing a piece of metal to the quartz crystals it should be possible to study the behaviour of the metal whilst oscillating and it is suggested that slip bands will be detected.

Opaque objects such as metals are more difficult to deal with than transparencies ; the source must be right, the silver film must be critically right and the lens must be suitable.

Metallurgical Applications

Mr. J. Holden discussed some of the limitations and advantages of the technique in certain metal applications. For the purpose of the less precise work, it is quite easy to adapt the metallurgical microscope so that the illumination is suitable for multiple beam interferometry, but the high precision aspect entails rather more optical care than practising metallurgists in general would care to undertake. With the ordinary metallurgical set-up, the 16 mm. lens is the most powerful that can be used.

The interference system used is that of the localised fringe system from a wedge interferometer and in order to get sharp fringes it is necessary to limit the wedge angle to something like 5°. It follows, therefore, that small details, which may cause local steep wedge angles, are not suitable for high precision work : in fact the lowest superficial extension acceptable is of the order of 1/200 mm.

The technique of silvering, an art that has to be acquired, is of prime importance as the surface reflectivity of the optical flat affects the quality of the fringes produced. In determining the reflectivity required, the reflectivity of the metal surface has to be taken into consideration.

A further point of importance is the preparation of the specimens. Ideally, over large areas the surface should be an optical flat, otherwise confusing fringe systems will result. Furthermore, all scratches must be removed : it will be seen therefore that good as is the normal metallurgical polish, something better is needed for high precision work.

Mr. D. G. Nickols then described an abrasion test in which the abrader is a cast iron wheel of 120° included angle. It is diamond charged and the specimen is held against it for a known number of revolutions at a known load. Examination of the cavity by multiple beam interferometry shows it to have an included angle of about 170° although the included angle of the wheel is only 120°. Furthermore there is no evidence of build-up round the rim, this indicating that it is a pure abrasion cut.

To date, work on hardness tests has been carried out on fine-grained metals and on martensitic steel no evidence of slip planes has been found. Future work will include metals such as tin, with a large grain-size, on which it is hoped to see slip and twinning.

Discussion

As a possible field of usefulness for the technique, Dr. A. Taylor suggested the study of magnetostriction at elevated temperatures, with the interferometer connected by an extension rod to the specimen in the furnace. Mr. Nickols pointed out that direct measurements at high temperature would be rather difficult due to the tendency for the silver film to coagulate and also to tarnish.

The possibility of using the method to study the state of strain surrounding separating particles in steels and other alloys was suggested by Mr. E. H. Bucknall. Whilst this might be possible in certain cases it has to be borne in mind that the region must be at least 1/200 mm. wide for reasonable results.

Considerable discussion took place on the question of slip—whether rotation occurred—and although many arguments were advanced in favour of pure block slip, Professor Tolansky remained unshaken in his belief that rotation also took place. Mr. Reason compared the sensitivity of methods in which a stylus was used with the use of a Zeiff-Limik interperometer and raised the general question of the limitations of the multiple-beam technique, while Mr. Crook asked Mr. Holden to clarify the consequences which followed the use of materials with a low reflecting co-efficient.

General Discussion

The Conference was concluded with a general discussion in which a number of other techniques were considered.

The metallurgical polarising microscope has been used with conspicuous success by Mr. H. Morrogh in the examination of cast-iron specimens and with the aid of a number of slides he demonstrated its effectiveness in distinguishing between otherwise similar constituents and in facilitating recognition of constituents.

Mrs. P. G. Dunsmuir described a novel application of polarised light based on the fact that light reflected at normal incidence from an isotropic or cubic crystal does not produce ellipticity whereas oblique reflection does. It is important to know the orientation of the grains in electrical sheet steel. After etching with special reagents, which expose only cubic faces, the surface of crystals with [100] planes parallel to the plane of polish will reflect the light without ellipticity whereas the stepped nature of other crystals will result in two-fold oblique reflection with accompanying ellipticity. In this way the [100] planes can be determined.

A method of making plastic replicas of surfaces which cannot be cut up, or are inaccessible to instruments, was described by Mr. M. R. Hopkins. A drop of liquid is placed on the metal surface and polymerised *in situ* by shining ultra-violet light on it. Before polymerising, a piece of $\frac{1}{8}$ in. plastic sheet is pressed on to the liquid so that the replica may be lifted up without damage. In this way it is possible to check surface finish, by using the Talysurf on the replica, and to study the microstructure.

Attention was drawn, by Mr. W. C. Heselwood, to a technique developed in Germany for stereoscopic micro-radiography. In thanking Mr. Heselwood, Dr. Conn said that the sub-committee proposed to cover the whole of the electric-magnetic spectrum and they would be grateful for having their attention drawn to techniques which might prove worthy of consideration.

Packaging of Engineering Equipment

(*continued from page* 272)

mechanical causes, and correct slinging and lifting of cases are described. Cautionary markings in various languages, including the equivalents of "this side up," "handle with care," etc., are given.

Brief notes are included as a guide to the conditions of goods handling in various parts of the world.

Section II—Packaging Materials and Methods

Cleaning and Drying

Cleaning, according to the usual workshop interpretation of the word, is rarely a satisfactory preparation for the application of chemical preservatives. The material of the product, the type of surface, the size and shape of the product, and the nature of the foreign matter to be removed, are factors influencing the choice of cleaning method. Various methods, including the use of White Spirit, Methanol, and Trichlorethylene, are described in detail together with the type, cost, and suppliers of the materials and equipment required. Methods of rust removal and drying are also discussed.

Preservatives

The composition of the metal rarely influences the choice of preservative, but the surface of the metal part is of great importance in this connection. Choice of preservative is also influenced by accessibility of the parts to be preserved, both for applying the preservative and subsequently removing it. Preservation must be correlated with packing and wrapping to avoid waste in packaging materials.

The use of various types of preservatives, including hard film, soft film, and oil film, are described. Equipment cost and suppliers are listed in detail. The use of water displacing fluids for addition to soft and hard film preservatives of all types is described. Information is also given on the application of hot melt strippable plastic coatings which have been found to be an excellent packaging medium as well as a corrosion preventive for the packing and storage of small tools, gauges and instruments. Although the cost of the plastic is considerably higher than that of the ordinary hard film preservative, the bulk of the packaging materials usually used for the packing of tools and gauges can be dispensed with, leading to increased economy.

Wrapping Materials

Recommendations are given regarding the use of greaseproof paper, waxed paper, and aluminium foil, and advice is given on the selection of the best wood for cases. Descriptions are given of tensional steel strapping for increased strength, case lining for increased protection, and cushioning materials, including wood wool, flax rug, pressed felt, corrugated paper, and sponge rubber.

Desiccants are recommended for taking care of excess moisture inside sealed containers, and brief notes are given of adhesives and adhesive tapes.

Reference is also made to the process which consists of pressing several layers of plastic coating over the product before it is actually packed.

Section III—Choice of Packaging Methods

In this section, methods recommended for the packing of machine tools, small tools, gauges, and instruments, are discussed in detail. Although the recommendations given refer to specific types of engineering equipment, the advice is applicable to a much wider field of engineering manufacture. The manufacturer of special machines will find that the chief recommendations made for machine tools will also apply to his own product. Similarly the discussion on the packaging of small tools and instruments contains data which will be useful for packing most other types of small engineering components and instruments.

Packaging of Machine Tools

Machine tools and similar machinery require protection against attack by weather, sea spray, condensation, etc., and against mechanical damage caused by accident, neglect or mishandling. Recommendations for preventing such damage include :—

(1) Instructions for the application of suitable preservatives.
(2) Cleaning and drying procedure.
(3) Choice of preservative, remembering that there is often danger of the preservative being carried into working parts of the machine, such as sliding surfaces, gear teeth, screws and nuts, where jamming might be caused.
(4) Consideration of individual elements of a machine for packing purposes, principally discussing them under three groups, namely, non-bearing surfaces, exposed bearing surfaces, and enclosed bearing surfaces.
(5) A discussion on the relative merits of ventilating and sealing, a fundamental consideration in machine tool packing. The chief merit of a sealed container is that it can give complete protection against corrosion. The properly designed and ventilated unsealed case can, however, be successfully employed with greater economy in many circumstances.

The general principles of the construction of machine tool cases are given with the assistance of illustrations and refers specifically to the case base, ends and sides, lid, case assembly, ventilation, nailing, location of machine tool, and exterior case fastenings.

Packaging of Small Tools and Gauges

The packaging of small tools, although usually a simpler process than the packaging of machine tools, has its own problems. Nearly all components classified as small tools and gauges require more than mere surface protection against rusting ; they must also be adequately protected from mechanical damage to their edges or surfaces due to shock. The most economical way of doing this would be to apply preservatives which incorporate both the right corrosion-preventing properties for the type of surface concerned, and also sufficient cushioning properties to prevent scratching or chipping. It is chiefly with this consideration in mind that the specific recommendations given in this section have been included.

The importance of the preliminary processes of cleaning and drying are emphasised. The selection of the best method usually depends on the circumstances in each works, but some of the factors affecting this selection are enumerated.

For the preservation of cutting tools, the choice of preservatives lies between hard film preservatives, permanent soft film preservatives, and hot melt strippable plastic coatings. Details of the advantages and disadvantages of the latter method are stated to assist the manufacturer who may be contemplating changing to this method.

Due to the high degree of accuracy and quality of finish to which surfaces of precision tools and gauges are usually manufactured, the preservative used in the protection of such surfaces from corrosion must fulfil two requirements. Firstly, it must entirely prevent any corrosive or staining action which would impair the quality of the surface, and secondly, its method of application, its cushioning properties, and its method of removal must be such that throughout the three stages of its use, namely, application, transit period, and removal, there is no possibility of damaging the surface. In special cases, such as the preserving of slip gauges and other valuable parts, special precautions are often necessary, and boxes and corrugated cardboard used for such components must be free from acidity. Precautions should be observed in using string for tying the wrapping papers.

All aspects of construction and material for packing cases and boxes as applying specifically to small tools and gauges are described.

Packaging of Precision Instruments

The recommendations relating to the packaging of precision instruments apply chiefly to mechanical, optical and electrical measuring instruments, such as projectors, comparators, optical tables, dividing heads, toolmakers' microscopes, etc. Adequate protection of such instruments from damage due to corrosion, fungus, and shock has in the past presented many manufacturers with considerable difficulties. Some of the methods by which these packing problems can be overcome are given in this section, and include recommendations relating particularly to preservation, tropic proofing, protection from shock, and construction and assembly of cases.

Appendix

The appendix includes a very useful list of names and addresses of suppliers of packaging equipment and a bibliography containing reference to some of the many sources of detailed information on packing cases, preservatives, etc.

Promising Lead Ore Lode Found In Greenland

A party, comprising 32 Swedish geologists, prospectors, miners and airmen is accompanying a Danish Government expedition to East Greenland where, last year, the Danish Dr. Lauge Koch made sensational discoveries of lead ore and other minerals in huge deposits in King Osca Fiord on the coast. At one place, on the edge of the inland ice, large quantities of 84% lead were exposed to full view, and it is estimated that at this site alone 1,000,000 tons of lead could be mined, which means the world's largest lead ore lode.

The Swedish experts will check up on Dr. Lauge's observations. The Boliden Company, one of Sweden's foremost mining and prospecting concerns, has placed some of its most capable staff members at disposal. Dr. Josef Eklund of the Swedish State Geologic Survey is heading the special prospecting party.

Wiggin Nickel Alloys

" Wiggin Nickel Alloys," published by Henry Wiggin and Co., Ltd., Wiggin Street, Birmingham, 16, in August, contains a number of interesting articles, among which Monel figures prominently. Bee keeping, ice-cream manufacture, laundry equipment, foundry practice, hot drink and food containers, oil and petrol strainers and water distillation, are subjects featured in illustrated articles. Articles dealing with the use of Inconel, cupronickel and thermometals also appear in this issue.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

RECENTLY, when doing some rather overdue filing of references, we discovered that during 1948, in about forty of the more important scientific journals, nearly four hundred papers were published that might fall into the category of inorganic analysis. This is some measure of the amount of current reading that has to be dealt with if one is to keep abreast of the literature. But here we have only a part of the story. There are many more references of which one must be aware, as can readily be seen by glancing at Section C of the British Chemical Abstracts. In addition, unless one has a phenomenal memory, some mode of filing references must be adopted. Several publications have dealt recently with various ways of filing which are claimed to be relatively simple and, at the same time, comprehensive. To the writer it has seemed, for some years, that the Universal Decimal Classification should provide a basis which would not only be logical, but would also permit ready exchange of information. One abstract journal, indeed, already indexes its abstracts on this system as a convenience for its readers. With this system, however, the user is often forced to fall back on his ingenuity in an effort to extend the classification logically and to modify it to suit personal needs. We would be much less dogmatic about the most satisfactory filing system than we would have been ten years ago. The one point on which we are certain is that it is little short of disastrous, with the present-day rate of publication, to allow one's filing to lapse even for a short time.

The Sub-micro Balance and its Applications

Part II—Technique and Applications

By G. Ingram

Centrifuge separations, precipitation procedures, and various types of volumetric and gravimetric techniques on the sub-micro scale are described.

(*Continued from page* 231)

Separations by Means of the Centrifuge

Collection of an insoluble substance such as silver halide by filtration cannot be attempted on the sub-micro scale. This type of reaction may be carried out in weighed reaction cones which are then centrifuged. In this manner many ordinary micro methods involving the collection of a precipitate may be scaled down. Owing to the fact that this involves a reduction in volume and not concentration, a precision of the order of 0·5% is readily obtainable.

The technique for the collection and weighing of a precipitate is as follows: The test solution is introduced into a weighed cone. Solids are weighed into a cone and then dissolved in a drop of solvent. The cone is then placed inside a 6 cm. length of 0·6–0·7 mm. bore capillary tubing and centrifuged using a micro cone with a narrow tip as a holder (Fig. 5). The capillary is withdrawn and by gentle tapping the reaction cone is removed from it, stem first, clamped in the manipulator and inserted into the moist chamber (Fig. 3).

The required amount of reagent solution is then added to the cone. In order that precipitate does not adhere to the tip of the capillary pipette whilst the reagent is being introduced, it is so placed as shown in Fig. 6A that an air bubble separates the two solutions. The cone is then recentrifuged which mixes the two solutions, completes precipitation, and separates the solid. The cone is returned to the moist chamber in order to remove the liquid with a fine capillary tip, and to add a drop of wash liquid. The centrifuge procedure and removal of wash liquid is repeated as above, the cone returned to its outer sheath, dried, and reweighed. To dry the cone the sheath is placed in a 5 mm. bore tube through which a slow current of dry air passes, and which is warmed with the tip of a micro burner (Fig. 6B). Drying for 3 mins. is usually sufficient.

Precipitation by Means of Gases

Precipitation of a metal ion can be accomplished using a technique described by Benedetti-Pichler[7] whereby a gas is employed to form an insoluble substance suitable for collection and weighing in a reaction cone. Sulphide reactions are typical of this application.

The apparatus needed is shown in Fig. 7. A 5 mm. bore glass tube A, drawn out to a capillary of about

7 Benedetti-Pichler, A. A., "Micro-Technique of Inorganic Analysis," 1942, page 161.

1 mm. bore, is bent to the shape shown. The constriction B is formed before the cone C is introduced, and the tip at the top of the capillary D after its introduction. A plug of cotton wool is inserted into the 5 mm. bore tube which is connected to the gas generator. Gas is passed through the apparatus to displace the air and the tip D sealed off and then the constriction B drawn off from the wider portion. The capillary is placed in a beaker of water at 70° C. for about 30 secs. to complete reaction, and then cut open to remove the reaction cone for further treatment.

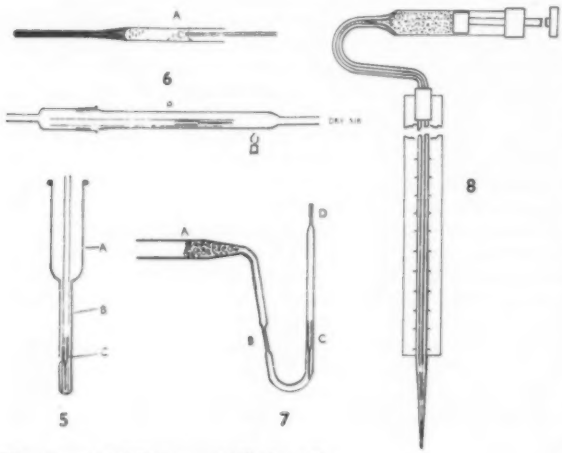

Fig. 5.—(A) Micro-centrifuge tube.
(B) Capillary sheath.
(C) Reaction cone.

Fig. 6.—(A) Method of inserting reagent solution into the reaction cone.
(B) Apparatus for drying reaction cones.

Fig. 7.—Apparatus for precipitations by gases.
Fig. 8.—Rehberg burette.

Ash Determinations

The higher maximum load of the quartz submicro balance allows the determination with 10–100 μg. of sample of metals in organic compounds. The material is ashed in small platinum crucibles.

The noble metals and those metals producing oxides are readily determined this way, but extreme caution is necessary when those metals which are estimated as sulphates are attempted. Owing to the smallness of the crucibles, loss of some of the contents due to spurting of the sulphuric acid may occur.

Platinum crucibles are prepared from discs of thin foil weighing between 10 and 20 mgm. They are shaped with a glass rod using a half-bored rubber bung as a mould. The diameter of the bore is about 3 mm. and its depth about 4 mm.

The procedure is similar to that required for larger amounts of material. The dilute acid is added to the previously weighed crucible and sample with a fine capillary attached to the syringe. In this case the tip of the capillary is bent downwards so that the acid is easily introduced into the crucible. The crucible is heated by placing it at one end of a strip of thick platinum foil 50 mm. long and 6 mm. wide, suitably fixed in a horizontal position. Heat from a micro-burner is applied at the opposite end of the strip and the flame gradually moved up towards the crucible until all the contents have ashed, or the acid evaporated off. The flame is then held underneath the crucible for two or three seconds, which is then allowed to cool before weighing.

Volumetric Technique

Other volumetric procedures than those already mentioned are applicable on the submicro scale. Thus, several gamma of an organic acid dissolved in a single drop of solvent may be titrated with 0·01 N caustic soda. A burette suitable for this type of work has been designed by Rehberg.[8] The titration may be carried out in the depression of a microscope slide, stirring being achieved by a glass thread operated by an electro-magnetic device.

The burette (Fig. 8) which has since been modified by Kirk[9] consists of a vertical thick walled capillary tube. The bore is about 0·9 mm. having a capacity of 0·1 ml. for every 200 mm. length (this is approximate). The lower end is drawn down to a fine tip which is always immersed in the liquid being titrated. The upper end is bent into a loop and widened out to form a mercury reservoir. The reservoir is closed by a plug holding a screw which when manipulated expels liquid from the tip of the burette. The burette is filled in such a manner that an air space separates from mercury. This liquid produces a lag in expulsion of liquid when the screw is operated because compression of the air space occurs. The titration has, therefore, to be carried out with great care especially towards the end.

Calibration of the tube is made by measurement of a weighed drop of mercury at various points. A scale is then evaluated from the results and fixed behind the capillary. An accuracy of $\pm$ 0·3% is obtained, titrating volumes of liquid of the order of 0·01–0·2 ml.

Weighing Technique

Because of the small weight differences involved, great care must be taken and the utmost cleanliness observed during all operations. The various glass capillaries must be prepared from perfectly clean quill tubing and when made, sealed into larger bore capillary tubes until required. A useful range of micro blow lamps for making the small apparatus has been described by Stock and Fill.[10] Reaction capillaries and other apparatus to be weighed on the balance must only be handled with shaped forceps. The pipettes and other delicate apparatus must be handled only with fingers which are covered with cotton gloves.

8 Rehberg, P. B., *Biochem. J.*, 1925, **19**, 270.
9 Kirk, P. L., *Mikrochemie*, 1933, **14**, 1.
10 Stock, J. T., and Fill, M. A., *Anal. Chim. Ac a.*, 1948, **2**, 281.

Mr. H. WILLIAMS, of Messrs. Sterling Metals Ltd., Coventry, retired at the end of July after 29 years as Director and Secretary. Following a Board Meeting on July 26th, a luncheon was given by his fellow Directors at the Hall Hotel, Keresley, and an inscribed silver salver was presented to him. Mr. Williams will be succeeded as Secretary by Mr. T. BARKER.

Dr. J. H. WHITELEY has retired from the Consett Iron Co., Ltd., Consett, Co. Durham.

Miss DOROTHY PILE, A.I.M., has been elected President of the Birmingham Metallurgical Society. On the Staff of the Design and Research Centre, Goldsmiths' Hall London, Miss Pile is the first lady president since the formation of the Society in 1903.

Metallo-Organic Reagents Used In Micro-Analysis

I—The Determination of Bismuth and Cadmium

By F. Lester

Certain metallo-organic reagents can often be used with advantage in the determination of metals on the micro-scale because of the favourable conversion factors they supply. Such reagents for the determination of bismuth and cadmium are reviewed in the following article.

IN gravimetric analysis on the micro-scale the final form in which the particular element or radical being determined is weighed, must be selected with great care. The compound chosen should contain as little as possible of the required constituent in order to reduce weighing errors. These conditions should as far as possible be aimed at in macroanalysis, but their attainment is not quite as necessary. When the heavier metals are being determined it is difficult to select from the purely inorganic compounds, final weighing forms in which the metals exist in relatively small proportions and it is then necessary to fall back on more complex compounds which are more likely to possess the characteristics required.

The problem may not be solved by the use of a purely organic precipitant, for the molecule may not be sufficiently large to yield a favourable conversion factor. In any case the main purpose in using such precipitants is because of their specific or selective nature and the suitability of the weighing form is of secondary importance. The type of complex compound most likely to yield a precipitate possessing a low conversion factor is that consisting of both inorganic and organic radicals. Examples are cobalt ethylenediamine chloride which may be used for the determination of bismuth[1, 2] and other metals, phenyl trimethyl ammonium iodide for the determination of cadmium[3] and chromium ethylenediamine chloride for the determination of antimony.[4] Unfortunately these precipitants are not very selective in their reactions, and it is often necessary to separate interfering metals prior to the final precipitation. Nevertheless, such compounds have a definite value since the precipitates obtained usually have very favourable conversion factors, and filtration and drying may be effected very soon after precipitation. In some cases effective separations can be achieved even in the presence of metals possessing similar characteristics. In most cases the final determination is made gravimetrically because of the advantages already discussed, but in a few particular cases a volumetric completion to the determination may be applied.

The use of these reagents as applied to the determination of certain metals is discussed in the present review.

Bismuth

Precipitation with cobalt ethylenediamine chloride.[3]—A solution of the bismuth salt, dissolved in hydrochloric acid (1 : 50) is treated with excess of potassium iodide. A concentrated solution of cobalt ethylenediamine chloride ($Co\ en_3$) Cl_3, $2\ H_2O$ (where en = ethylenediamine) is added, 0·3 g. of reagent being used for each 0·1 g. of bismuth present in 100 ml. of solution, and the mixture heated to boiling. A reddish-yellow precipitate of ($Co\ en_2$) $I\ (BI_4)_2$ is formed. This is filtered and washed, first with a wash solution containing potassium iodide and cobalt ethylenediamine chloride, then with alcohol and finally with ether. The precipitate is dried in a vacuum desiccator and weighed. It contains 23·24% of bismuth.

Cobalt ethylenediamine iodide may be used in place of the chloride.

Precipitation with cobalt diethylenediamine dithiocyanato thiocyanate.—Spacu and Spacu[5] have also determined bismuth by precipitation with the above reagent ($Co\ en_2\ (CNS)_2$) (CNS) in presence of potassium iodide. The conditions are similar to those used in the previous method. The precipitate formed ($Co\ en_2\ (CNS)_2$) (BiI_4) contains 20·65% of bismuth.

Precipitation with hexamethylenetetramine.—A precipitate of BiI_3 ($(CH_2)_6\ N_4I)_3$ is formed when a nitric acid solution containing bismuth is treated with hexamethylenetetramine and potassium iodide.[6] The precipitate may be weighed or treated with excess standard silver nitrate and the unconsumed silver back-titrated.

Precipitation with tetrasecetyl ammonium hydroxide.—Tetrasecetyl ammonium hydroxide reacts with bismuth salts in the presence of potassium iodide to yield the insoluble red compound $(C_{16}H_{33})_4\ NI.BI_3$[7]. If iron is present its interference can be masked by addition of a solution containing formic acid, ammonium formate, potassium iodide and sodium sulphite.

Precipitation with α-naphthoquinoline.—In strong mineral acid solution, α-naphthoquinoline reacts with bismuth in the presence of halide ions to give an insoluble compound[8]. Mercury, copper, cadmium, uranium and ferric iron behave similarly. Nevertheless some separation can be effected by changing the particular halide present. In the presence of chloride, only mercury and bismuth are precipitated. In the presence of bromide or iodide, mercury, cadmium and bismuth are precipitated. In the presence of thiocyanate in sulphuric or nitric acid solution, ferric iron and uranium precipitate as the α-naphthoquinoline thiocyanates.

Bismuth is usually precipitated as $(C_{13}H_9N)\ H.BiI_4$. It should be present as the sulphate in a solution containing 3% of free sulphuric acid. Strict volume control

1 Spacu, G. and Suciu, G., *Z. anal. Chem.*, 1929, **79**, 196.
2 Dubsky, J. V. and Trtilek, J., *Chem. Obzor.*, 1934, **9**, 142.
3 Pass, A. and Ward, A. M., *Analyst*, 1933, **58**, 667.
4 Spacu, G. and Pop, A., *Z. anal. Chem.*, 1938, **111**, 254.
5 Spacu, G. and Spacu, P., *Ibid.*, 1933, **93**, 260.
6 Solodovnikov, P. P., *Trans. Kirov. Inst. Chem. Tech. Kazan.*, 1940, **8**, 57.
7 Girard, A. and Fourneau, E., *Compt. rend.*, 1925, **181**, 610.
8 Hecht, F. and Reissner, R., *Z. anal. Chem.*, 1935, **103**, 88.

of the solution is necessary otherwise incorrect results are obtained.

Precipitation with quinaldine.—Bismuth may be determined in the presence of lead, antimony, tin, cadmium, iron, chromium, manganese, cobalt, calcium, barium, uranium, nickel, beryllium, aluminium, titanium, zinc, sodium, potassium, arsenic and phosphate by precipitation with quinaldine in the presence of potassium iodide. As little as 0·3 mg. may be determined. Only silver and mercury, and chloride in large amounts interfere.[9]

The reagent consists of 150 ml. of quinaldine, 50 ml. of concentrated sulphuric acid and 75 g. of potassium iodide diluted to 1,000 ml. A wash solution consisting of 35 ml. of quinaldine, 15 ml. of sulphuric acid and 0·8 g. of potassium iodide diluted to 1,000 ml. is also required.

The solution is diluted to 200 ml. and the acidity adjusted to about 1N to sulphuric acid; 15 ml. of 10% sodium sulphite are added and the bismuth precipitated by adding the reagent drop-wise. After standing for 20 mins. with occasional stirring, the red precipitate is filtered and washed with 40–50 ml. of wash liquid, then with 30% acetone dissolved in butyl ether. The precipitate is then dissolved in 100 ml. of 5% sodium hydroxide, boiled for 20 mins. to decompose it completely cooled and neutralised with dilute hydrochloric acid; 10 ml. of concentrated hydrochloric acid are added and 8 ml. of 0·5M potassium cyanide. The solution is then titrated with potassium iodate using Lang's method.[10]

The reaction depends on the following :—

$$IO_3^- + 2\,I^- + 3\,HCN \rightarrow 3\,ICN + 3H_2O$$

1 ml. 0·025M $KIO_3 \equiv 2{\cdot}612$ mg. Bi

Precipitation with caffeine.—In a similar method to the above, bismuth is precipitated with caffeine in the presence of iodide.[11] The titration is done in exactly the same way. Mercurous, silver and cupric ions interfere, but mercuric ions are without effect.

Cadmium

Precipitation with brucine.—In dilute sulphuric acid solution, cadmium is precipitated by brucine in the presence of potassium bromide to give the complex: $[(CH_3O)_2C_{21}H_{20}O_2N_2]_2\,Cd.Br_2.2HBr$.[12] The method has been applied to the determination of cadmium in magnesium-aluminium alloys. Magnesium, aluminium, copper, zinc and manganese do not interfere.

0·3 g. of the sample are dissolved in 10–15 ml. of 20% sulphuric acid, evaporated to 5 ml. and the silica removed by filtration; 5 ml. of 1% brucine in 20% sulphuric acid, and 10 ml. of 10% potassium bromide solution are added in quick succession. The mixture is stirred vigorously, allowed to stand for 1 hour and filtered on a sintered glass crucible. The precipitate is washed five to six times with a solution prepared by mixing 40 ml. of 1% brucine sulphate, 30 ml. of 10% potassium bromide and 80 ml. of water, and then with alcohol-ether mixture (1 : 7). After drying at 130°–150° C. for 30 mins. the precipitate is weighed. The factor for cadmium is 0·092.

Cadmium may be determined in the presence of zinc by precipitation with brucine and potassium iodide.[13] The precipitate is finally titrated with silver nitrate using eosin Y as indicator.

Precipitation with pyridine.—When pyridine is added to a boiling solution containing cadmium and thiocynate ions, a stable white precipitate of $(Cd.Py_2)\,(CNS)_2$ is formed[14]. 1 ml. of pyridine is added to 50–100 ml. of the neutral solution containing 1·0 g. of ammonium thiocyanate and the mixture stirred well. After cooling, the white precipitate is filtered on a filter-crucible and washed four times with a solution prepared by mixing 73 ml. of water, 25 ml. of 95% alcohol, 2 ml. of pyridine and 0·1 g. of ammonium thiocyanate. It is then washed further with a 10% solution of pyridine in alcohol and finally with 15 ml. of ether containing 2 drops of pyridine. The precipitate is dried *in vacuo* for 10 mins. and then weighed. The factor is 0·2907.

Vornweg[15] uses a similar method but converts the complex to $(Cd.Py_4)\,(CNS)_2$ thus improving the conversion factor.

Precipitation with β-naphthoquinoline.—Cadmium is precipitated by β-naphthoquinoline and potassium iodide to give the compound $(C_{13}H_9N)_2\,H_2Cd.I_4$.[16] Tartrate and iodide prevent tin or antimony being precipitated. α-naphthoquinoline has similar analytical properties (see Bismuth).

To the neutral solution containing cadmium, 50 ml. of 2N sulphuric acid and 50 ml. of 10% sodium tartrate solution are added. A slight excess of β-napthoquinoline reagent is added (2·5 g. in a mixture of 1·3 ml. sulphuric acid and 3 ml. of water, diluted to 100 ml.) and a little sulphurous acid and the solution diluted to 150 ml. A slight excess of 0·2N potassium iodide is added and the mixture allowed to stand for 20 mins. The white precipitate is filtered and washed free from acid with a solution made by diluting 10 ml. of reagent to 90 ml. with water, and adding 10 ml. of 0·2N potassium iodide solution. The precipitate is decomposed by heating with 20 ml. of 2N sodium hydroxide solution, made slightly acid with sulphuric or hydrochloric acid, and further acid then added to make the acid concentration about 5%. The solution is then titrated by the Lang method[10] or by the Berg[17] iodine-acetone method.

Pass and Ward[3] have described a method based on the above which enables cadmium to be determined in the presence of all the other metals in the second analytical group. Zinc may be determined in the filtrate.

Precipitation with ethylenediamine.—Cadmium is precipitated in the presence of potassium iodide by the addition of copper ethylenediamine nitrate, prepared by heating 1 mole of copper nitrate with 2 moles of ethylenediamine till a crust forms.[18] Cadmium is determined by adding the hot concentrated reagent to a boiling solution containing excess potassium iodide. The precipitate is washed first with a solution containing 1% potassium iodide and 0·3% of copper ethylenediamine nitrate, then four to six times with 2 ml. portions of alcohol and finally three to four times with 2 ml. portions of ether. The precipitate is dried *in vacuo* and weighed. The factor is 0·1396.

Precipitation with phenyl trimethylammonium iodide.—When phenyl trimethylammonium iodide is added to a solution containing cadmium the complex $(C_6H_5(CH_3)_3N)_2\,CdI_4$ is precipitated,[3] Pass and Ward have described a procedure enabling the determination to be made in the presence of several other metals. The determination is completed by the Lang titration.[10]

9 Hayes, J. R. and Chandlee, G. C., *Ind. Eng. Chem.* (*Anal.*), 1939, **11**, 531.
10 Lang, R., *Z. anor. allgem. Chem.*, 1922, **122**, 332.
11 Beale, R. S. and Chandlee, G. C., *Ind. Eng. Chem.* (*Anal.*), 1942, **14**, 43.
12 Nikitina, E. I., *Zav. Lab.*, 1938, **7**, 409.
13 Thompson, T. L., *Ind. Eng. Chem.* (*Anal.*), 1941, **13**, 164.
14 Spacu, G. and Dick, J., *Z. anal. Chem.*, 1928, **73**, 279.
15 Vornweg, G., *Ibid.*, 1940, **120**, 243.
16 Berg, R. and Wurm, O., *Ber.*, 1927, **60***B*, 1664.
17 Berg, R., *Z. anal. Chem.*, 1926, **69**, 342, 369.
18 Spacu, G. and Suciu, G., *Ibid.*, 1929, **77**, 340.

Decorative Electroplating on Aluminium

By Glenwood J. Beckwith

THE older base metals have been plated successfully for many years but platers have experienced difficulties in obtaining satisfactory plated coatings on aluminium. As a result of the combined efforts of the foundry man, the polisher, and the plater, with due acknowledgment of the contributions of the metallurgist and chemist, commendable progress has been made in dealing with aluminium products.

Die-casting foundries have produced zinc items for some years that have been satisfactorily polished and plated. When zinc die-cast machines are used to produce aluminium items for plating, trouble seems to start. Many foundries whose products are usually sold with a ball burnished or painted finish suddenly discover that a high polish with a modern bright electroplate reveals surface imperfections that seemingly never existed. Blasting and burnishing operations tend to peen and cover up surface discrepancies. Painting actually hides all small defects by filling them up with pigment.

Greasing and buffing operations replace the above finishing steps when aluminium items are to be plated. These operations will reveal major surface defects such as flowers, cold shuts, misruns and the like. But oftimes the polisher is unable to see fine surface porosity, for usually his belts and wheels tend to smooth over such discrepancies. Actually the polished article may look smooth when reflected to ordinary light. Yet after alkaline cleaning, especially if improperly done, close visual inspection will reveal surface pits.

There are several commonly known procedures for polishing and buffing aluminium die-castings. The usual polishing methods, such as greasing with belts or wheels using grease-base polishing compounds, is not suitable for the general run of the foundry castings that are to be plated. Using an emery belt with a suitable oil, which does not load up like a solid lubricant, has proved highly successful. This operation is followed by a wheel operation wherein greaseless compounds are used. The castings should be immediately submerged in a high flash-point solvent followed by degreasing in a vapour type unit. The colour-buffing operation is best performed using a "dry" greaseless compound, because any porosity that may exist on the original aluminium surface, due to improper casting or excess greasing, machining, or "skin" destroying operations, will not become embedded with caked, greasy solids. The heat created during a severe greasing operation and the surface pressure of the buffing operation, especially if done on automatic machines, causes grease type compounds to quickly dry in any porous area. The plater may successfully coat these minute pores but, eventually, blistering may develop under the plating.

Extruded aluminium tubing, round or hexagonal, which is required to be electroplated, may be polished in the same way as die-castings, but, since tubing is thin, heat cannot be dissipated readily and warpage may occur. Relatively short lengths of hexagonal tubing will warp from the end pressure of holding jigs. A water-base liquid polishing compound is preferred over a grease type liquid compound in the case of tubing. This eliminates smudge and fire-hazard.

Stampings may be handled in the same manner as extrusions. Rolled material in stamped form can readily be polished and buffed on an automatic or semi-automatic machine. As in the case of other metals, irregularly shaped parts of the stamping may be finished by a hand polishing operation.

Many aluminium castings and small stamping do not require a mirror finish after plating, and need only be ball-burnished smoothly and plated. Plumbing supplies, such as small key handles, open wheel handles, solid wheel handles, etc., may require a bright brass finish or a copper-nickel chrome finish but not necessarily mirror-like.

The usual procedure after die casting or stamping is to ball burnish in lined barrels using small steel shot in soapy water. The time required is dependent on the type of article and the amount of feathers, flashings, or burrs to be removed. Rather than wash the finished items in solvent and vapour degrease, it is advisable to warm water rinse and follow with a quick dry. Thus the castings are void of any soapy or oily film and if plated soon after burnishing little difficulty will present itself in the cleaning, etching and pursuant plating operations.

This method of brightening is the most ideal and, if suitable to the user of the plated articles, it should be used whenever possible. The field of ball burnishing aluminium is being rapidly explored and, to the writer's knowledge, has gone so far as to smoothly burnish large, sharp-edged pieces by racking them and placing the racks in barrels. Thus the danger of surface nicking is eliminated. By having various barrels employing different media, the racks are transferred from the coarse barrels through to the finest.

Polished items may be vapour degreased prior to racking or they may be treated in a soak cleaner after racking if vapour degreasing facilities are not available. A combination of the two is desirable, the former being preferred. Ball burnished items need neither.

The soak cleaner can be any one of several types recommended by detergent manufacturers. They should be of the "non-etch" variety. A few minutes soaking at 170° to 180° F. is usually sufficient to loosen any stubborn foreign material. It is important to note at this point that if proper precaution is exercised in the polishing shop the amount of polishing material left on the item should be at an absolute minimum.

There are several "non-etch" cleaners available; it is being found, however, that on polished and buffed material, some are too mild, even when carried in fairly high concentrations and at temperatures near 200° F. A combination of "non-etch" and "etch" type, allows one to secure a very slight white etch on aluminium sand castings or stampings, or a slight

From *Metal Finishing*, 1949, **47**, 48–54.

discolouration on copper-silicon aluminium alloy die-castings. If a straight "etch" type cleaner is used at 160° F. with 5 oz. per gallon content, the cleaning cycle has to be short, but it requires a very dense surfaced casting to withstand even this. The longer the cleaning cycle the heavier the etch becomes, and, if polished beforehand, the bright platings that follow will reveal over-etching.

A good practice on ball burnished items is to clean chemically in the alkaline cleaner until gassing starts. After five seconds of gassing sufficient etch is obtained to insure cleanliness and still not impart dullness after plating. On polished items, the first indication of uniform gassing is sufficient and the work should be removed at once. In no instance should aluminium items be allowed to be cleaned in a zinc cathodic cleaner, if the latter is to be used again on zinc, for eventually severe blistering will occur on the zinc.

Many parts contain recesses, cavities, threads, etc. Extreme care in rinsing is probably more important with aluminium than in the case of other metals. Neutralising baths are advisable. All rinse tanks in the plating set-up should be equipped with high pressure fan-type sprays. The lower body of water in the rinse tank proper is kept warm with open type heating, such as small (3/32 in.) holes spaced about 1 in. apart. The condensate is always clean, and rapid and efficient heating is obtainable in the tank.

There are several recommended procedures for pickling aluminium, such as anodising in phosphoric acid, chemically treating in strong nitric-hydrofluoric acid mixtures, etc.

A highly successful practice used over a period of fifteen months in one plant has produced no plating rejects due to unsatisfactory pickling. The bath contains neither nitric nor hydrofluoric acid and is operated at less than 15% acidity. The work is made cathodic in the bath which operates at room temperature. A very high current density is used which produces a tremendous evolution of hydrogen. The mechanical scrubbing effect of this gas, plus the non-passivating effect, seems to assure 100% reception of chemical zinc from a sodium zincate bath or an electroplate if transferred directly to a nickel or chrome bath. Special precaution prior to direct plating must be observed, however, as hereinafter described.

A mild acid cathodic bath will operate practically indefinitely with small additions to take care of dragout and slow electrolytic break-down. Operated cathodically, very little rise in Baume is discernible, since the electrolytic treatment forces no metal into solution.

The immersion zinc-coating method has proved highly successful. It is somewhat expensive to buy in prepared salt form. This can be partly overcome by preparing the bath using caustic soda and zinc oxide. Considerable heat is generated when the caustic is dissolving and solution temperature should be checked after each sizeable addition. The zinc oxide can be added after the near-saturated solution of caustic is made up. A Baume of 40° at room temperature is desirable although the bath works satisfactorily at concentrations considerably lower. Upon re-cooling, the bath is in good condition. If the level is to be raised it should then be done with correct proportion of chemicals and allowed to cool before using again.

A steam coil should be installed in this bath. Shops set up to plate various types of base metals in the same monorail line will find that water drippage, unless the tank is covered, will eventually dilute the zincate bath. A steam coil allows for evaporating down to original concentrations and will re-dissolve most accumulations in the bottom.

Diffusion of Hydrogen Through Aluminium Tubes

By A. S. Russell

VERY little is known about hydrogen in solid aluminium, largely because of the very low solubility below the freezing point, but in general aluminium can be classed as a non-occluder of hydrogen. The most significant information has come from investigations of the rate of diffusion of hydrogen through aluminium. Some previous work by Smithells and Ransley is first reported. They found that the diffusion rate at 580° C. and 290 mm. increased from 2 to 10 × 10^{-1} (ml. N.T.P.) (mm. thickness) per (sq. cm. area) (sec.) when the surface was abraded in vacuum, but fell on continued heating in quite pure hydrogen to 1 × 10^{-7}, after which it was restored to its original high value by re-abrading. In the present study by the author the tubes (impact extrusions) were of aluminium containing 0·2% iron, 0·1% silicon and 0·01% or less copper, manganese and magnesium. A full description of the apparatus, diffusion procedure and results are given. The rate of hydrogen diffusion through the tube was measured at temperatures from 100° to 500° C. and at pressure of 1 to 75 cm. of mercury, and was found to change rapidly with time at moderate temperatures. The diffusion at 250° C. in one atmosphere of hydrogen diminished from 0·04 (ml. × 10^{-7}. N.T.P.) (mm. thickness) per (sq. cm. heated area) (sec.) to 0·000 after 20 hrs. heating at 350° C. Similarly extremes of 1·1 and 0·02 were observed for the diffusion rate at 500° C. Because of the high rate of decay, no significant data on the effect of temperature and pressure on the rate of diffusion of hydrogen through aluminium in its highly diffusing state were obtained.

The sample recrystallised and considerable grain growth occurred during these measurements. No large increase in total oxide film thickness was observed, although this does not eliminate oxidation as a major factor influencing diffusion rate. The rate was increased more than fivefold when a high-voltage discharge was passed through the hydrogen. The diffusion of oxygen at one atmosphere at 500° C. was immeasurably low. There appeared to be an appreciable diffusion of helium at 72 cm. and 500° C. in a single run, the rate being as great as that for hydrogen under the same conditions.

From *Metal Progress*, 1949, **55**, 827–831. Reproduced from *Light Metals Bull.*, 1949, **11**, No. 18.

STEELS IN GERMAN AIRCRAFT

COPIES of VOLUMES I & II of the above book are still available. Order direct from The Kennedy Press Ltd., 31, King Street West, Manchester, 3, Price 10s. 6d. post free for each volume.

Hardening Enhances the Properties of Malleable Cast Iron

By Kenneth Rose

MALLEABLE iron responds well to heat treatment, although the advantages to be obtained by heat treatment are not as widely used by industry as they might be. Malleable iron can be given a hardness approach-that of the tool steels by proper heating and quenching, and this hardness can be drawn back similar to the treatment for hardened steel. The process greatly enhances the value of malleable iron for many applications, and classifies the iron with the engineering materials rather than with the purely structural materials.

Malleable iron is the lowest-priced shock-resistant metal available to industry but its ductility means that it is relatively soft, and for some applications it is desirable to harden the material that has been put through a malleabilising process to achieve this softness. It is hardened to impart wear resistance or increased strength to a component that must be primarily shock resistant; hardening is therefore, almost exclusively either local or surface hardening.

All malleable irons can be hardened, but hardening brings certain limitations that tend to restrict both the type of hardening process and the type of malleable iron to be used. As hardening is accomplished over a limited area or at the surface of the piece only, induction heating, flame hardening, or radiant gas heating involving short cycles is usually used. With induction heating the cycle might be only 1 to 4 sec. Flame hardening will usually require a substantially longer cycle. Selective hardening of malleables, therefore, requires the use of a metal that can be hardened in a matter of seconds. Therefore, the pearlitic malleables are the preferred materials.

Pearlitic malleable iron is quick-hardening because of its content of combined carbon, which is readily available for solution in austenite at temperatures of about 1,600° F. or higher. This combined carbon is present as cementite and must account for 0·30 to 0·80% carbon to permit satisfactory heat treatment in short cycles.

Malleable irons other than pearlitic can be heat treated also to secure greater hardness. In dealing with these metals, in which combined carbon is not available for quick solution, a first pass through the heating equipment is necessary to put the carbon into solution. A second pass and quench will then develop the hardness desired in the work. Spheroidal pearlitic malleable iron, in which the combined carbon is dispersed in spheroidal form, may require a heating pass preceding the hardening pass also, as the combined carbon dissolves more slowly in austenite from the spheroidal form.

Malleabilising may produce a decarburised surface, in which hardening would be erratic or incomplete. For this reason it is best practice to heat treat machined surfaces to develop high hardness. When the hardened surface must posses a degree of toughness, a tempering treatment on the hardened area will accomplish the desired result. A draw at about 600° F. will greatly decrease brittleness without lowering the hardness to the same extent. A hardness of about 52 to 57 Rockwell C may be expected with a good grade of malleable iron after this draw.

The pearlitic malleable irons are obtained by several variations in the malleabilising process that give incomplete graphitisation, so that some of the carbon is retained in combined form, usually as pearlite. The process of graphitisation can be interrupted, or retarded by an additive, or the completely graphitised metal can be reheated to effect partial resolution of the graphite content.

Graphitisation can be interrupted by shortening the annealing cycle during malleabilising. Whereas the malleabilising of cupola malleable iron requires about 6 days, some of the newer cycles for malleabilising require as little as 30 hr. Manganese may be used as the retarder, in amounts of 0·5 to 1·0% above the amount that would be used to produce a similar alloy in ordinary malleable iron. The manganese can be added to the iron in the ladle. In this case the metal is air quenched from above the critical, then spheroidised at about 1,325 F. Molybdenum can be used as a retarder also, in amounts of 0·15 to 0·20%. Chromium is an energetic retarder in amounts of 0·1 to 0·3% or less.

In general, the pearlitic malleables have a higher average yield point and higher ultimate strength than ordinary malleables. Elongation is lower, and hardness is higher. While the pearlitic malleables can be machined somewhat more readily than drop forgings or steel bar stock of the same hardness, it is slightly more difficult to machine than the standard malleables.

From *Materials and Methods*, 1949, **29**, 57–58.

Influence of the Top-Diameter on Fines in the Blast Furnace Charge

By Paul Reinhardt

EXPERIENCE has taught that an increase of the furnace efficiency by enlargement of its cross-section can not be obtained if the furnace mouth is not wide enough. But if the latter is enlarged and at the same time the gas velocity reduced, whilst both remain unchanged in the lower part of the shaft, it will have the effect that the pressure of the gas will be smaller at the furnace mouth than in the lower part of the furnace. Although the amount of dust would be smaller, the fine charge of the furnace would meet with an ever-increasing resistance, thus being stopped by the gas stream and collected in the furnace.

To clarify the question, whether this process could happen also at the usual furnace profile and under normal working conditions or under which circumstances this would be possible, a typical furnace was subjected to a calculation for quantity, composition, temperature and gas-velocity in the different levels of the shaft and subsequently the effective pressure of the gas flow upon the fine charge. The result was that the pressure is somehow greater at the furnace mouth than in the lower parts, and therefore, no dust accumulation in the furnace need be feared. The cross-section, however, already lies so near the admissible margin that its enlargement without a simultaneous enlargement of the lower diameter of the shaft, consequently an enlargement of the furnace angle, must give rise to serious concern.

The author gives many tables, diagrams and illustrations.

From *Stahl und Eisen*, July 21st, 1949, p.p 903–8.

Further Progress by Fescol Ltd.

THE official opening of a new factory at Port Glasgow, on September 13th, by Fescol Ltd. is a further indication of the rapid development and application of the service offered by this Company to the engineering and allied trades. This service comprises a method of applying certain non-ferrous metals to fabricated components in such a manner as to make the superimposed material an integral part of the base metal. By the method initiated and developed by the Company, this is achieved without the application of high temperatures, which might cause distortion and in some cases affect deleteriously the component itself.

Initially the process employed was used for making good deficiencies caused by wear and tear in service. It was soon realised, however, that an even greater field of usefulness was its application to improve new components by imparting a surface of a very high order to a comparatively cheap and easily worked base metal, and the name " Fescolising " quickly became associated with the repair of worn parts, the application of hard durable surfaces with low co-efficients of friction, and a high degree of corrosion resistance.

That the introduction of the process met a special need in the engineering field is indicated by the progress and expansion of the Company since its inception in 1920. From a small works in South East London it moved in 1926 to more commodious premises in Grosvenor Road. A French Company, Societe Fiscol, was formed in 1935 and a factory established in Paris. Since the Company supplies service on existing components, it was early recognised that works should be situated in key localities to reduce the delays and expense of transport. The first step in this direction was the establishment of a factory at Huddersfield in 1934. Continued progress necessitated more commodious premises and in 1941 the Karrier Works, Huddersfield, provided these facilities. In 1937 greater factory space was sought in London and in 1938 a move was made to the present address in North Road, London, N.7. These latter works are equipped with plant capable of dealing with components up to 6 tons in weight, with a maximum length of 20 ft. ; facilities for the deposition of nickel, chromium, and copper ; a machine shop which can handle the largest components from the deposition vats, and equipped with the most modern machine tools. The works are adequately staffed so that components sent for treatment can be put into service immediately on their return. The Company has its own research department where constant research and development are in progress.

In order to provide greater service facilities to the Company's many customers in Scotland efforts were made to open a further branch factory. It was necessary, however, to ensure that the key personnel for such a factory would be adequately housed. The Scottish Industrial Estates, Ltd., offered facilities and eventually a site was acquired for a factory at the Industrial Estate, Port Glasgow. The works erected on this site, and recently officially opened, covers an area of 16,000 sq. ft., and space has been reserved for further extension ; plans make provision, with the minimum of structural work, for a department in which heavier weights and greater lengths can be dealt with, but the new works, as at present constituted, can successfully undertake a wide range of work.

Staff Changes and Appointments

THE British Welding Research Association announce that Messrs. R. G. BURT and C. C. BATES have joined the Technical Liaison Staff of the Association.

Mr. J. G. BALL left the Association at the end of July to take up an appointment as Principal Scientific Officer at the Atomic Energy Research Station.

Mr. A. BARKER, who has been Secretary of the Association since 1946, is leaving at the end of August to take up an appointment as Assistant Director of the Federation of Boot and Shoe Manufacturers.

The following appointments are announced by the Railway Executive :—

Mr. T. M. HERBERT, M.A., M.I.Mech.E., Research Manager of the L.M.S. since 1932, to be Director of Research.

Mr. T. W. BROWN, M.B.E., M.I.Loco.E., formerly Chief of the Central Materials Inspection Bureau of the L.M.S., to be Materials Inspection Officer.

Mr. G. M. LEACH, formerly Assistant Marine Superintendent (Harwich Services), to be Assistant to Chief Officer (Continental).

Dr. W. I. PUMPHREY has been awarded a Commonwealth Fund Fellowship for study and travel in the United States.

Mr. J. E. ORTTON, sales promotion manager of Thos. Firth and John Brown, Ltd., has been awarded a Fellowship by the National Council of the Incorporated Advertising Managers' Association, for his long-standing service to advertising management and to advertising generally.

Dr. A. J. KESTERTON, M.Eng., Ph.D., F.I.M., has been appointed Melting Shop Manager at the new Abbey Works of the Steel Company of Wales Limited. He was previously with Messrs. Dorman, Long and Co., Ltd., where he held the position of Assistant Melting Shop Manager Acklam Works, Melting Shop Manager Redcar Works, and was finally seconded for special duties on the design and layout of the new Lackenby Steel-plant.

Mr. J. P. COLE, B.Sc., who was chief metallurgist at the Meltham Works of David Brown Tractors, Ltd., has taken up an appointment as senior assistant lecturer in metallurgy in the Department of Civil and Mechanical Engineering at the Huddersfield Technical College.

Mr. E. T. GILL joins Climax Molybdenum Company of Europe, Ltd. from October 1st as metallurgical engineer. After obtaining his initial industrial experience in ferrous metallurgy with Hadfields, Ltd. and Samuel Fox & Co., Ltd., Mr. Gill joined the firm of Bruntons (Musselburgh), Ltd. and was chief metallurgist there for four years. He served with the Aeronautical Inspection Directorate for two years and was then appointed to the metallurgical staff of Imperial Chemical Industries, Ltd. Early in 1943, Mr. Gill was seconded to Firth-Vickers Stainless Steels, Ltd., and in August, 1945, he joined Edgar Allen & Co., Ltd. as deputy to the chief metallurgist, Dr. Edwin Gregory. He was elected a Fellow of the Institution of Metallurgists in 1946.

Mr. E. W. COLBECK, M.A., F.I.M., Metallurgical and Research Director of Messrs. Hadfields, Ltd., East Hecla Works, Sheffield, has accepted an invitation to become a member of the Inter-Service Metallurgical Research Council.

Reviews of Current Literature

METALS HANDBOOK

Edited by Taylor Lyman. 1,444 pages with over 2,000 diagrams and illustrations, size 8¼ in. × 10¾ in. and bound in red cloth, price $15·00. Published by the American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio, U.S.A.

THIS latest edition of the well-known "Metals Handbook" is a remarkable achievement. In 1,268 pages of text, the compilers have managed to include the serious treatment of practically every branch of normal metallurgy. Despite the field covered, there is nothing superficial about the presentation, a fact vouched for by the names of those responsible. Moore deals with fatigue tests; Mehl with recrystallisation; Mathewson with the plastic deformation of iron, to mention only a very few. Many of the articles have been prepared by *ad hoc* Committees who have clearly taken their duties most seriously.

To give a general idea of the scope of the treatments one may cite the most interesting discussion of the basic causes of service failures in metals. It extends to some ten pages, is well illustrated and 99 references to original papers are included in the bibliography. The discussion of pyrometry extends to about 14 pages, and includes the use of photo-electric devices. As a typical page contains some 1,900 words it will be evident that the contributions are really "meaty."

After 19 pages of definitions—very well done on the whole, though there are inevitably some with which any reader might disagree—follow 12 of physical tables. Does the reader need the co-efficient of expansion of beryllium-copper, it is there; the densities of sintered carbides, they are there; the thermal conductivity of mullite, it is there; the vapour pressure of strontium, it is there, or the preferred orientation of drawn aluminium, it is there too.

To give some idea of the width of the field covered, may be mentioned an article of about 10,000 words on statistical methods as a guide in the control of operations and the quality of a product, one of 30,000 words on non-destructive testing, and one of 20,000 on salt- and lead-baths.

Ferrous and non-ferrous metals and alloys; refractory materials and fuels; chemical, physical and mechanical properties, all are considered. What more can any reviewer say than that there is here a unique volume, essential to all concerned with metals or their uses and, in view of both quantity and quality of the contents, probably the cheapest book on metallurgy ever produced.

F. C. THOMPSON.

THE FERROUS METAL INDUSTRY IN GERMANY, 1939-1945

By Geo. Patchin, formerly Principal of the Sir John Cass Technical Institute, London, and Ernest Brewin, Intelligence Officer of the British Iron and Steel Federation. Published for the British Intelligence Objectives Sub-Committee by H. M. Stationery Office, York House, Kingsway, London, W.C.2, 270 pp., price 4s. 6d.

Since the end of the war a large number of individual B.I.O.S., C.I.O.S., F.I.A.T. and J.I.O.A. reports have been published on many aspects of the German iron and steel industry during the war. Over 400 reports of this nature have been issued by H.M.S.O. and an imposing mass of foreign language documents have been accumulated in this country. However, the large number of reports issued, the unavoidably dispersed nature of the information and the inaccessibility of many of the German documents have made it a very difficult task to find a complete answer to any one query on German ferrous metallurgy, whether scientific, technical or industrial. In consequence, the iron and steel industries of the United Kingdom and the United States of America have been pressing for a detailed and comprehensive work of reference on development and progress in German ferrous metallurgy during the war years, when all international exchange of technical knowledge was suspended. This need has been fully met, through the Board of Trade and the Ministry of Supply, by the publication of the present volume.

As will be readily understood a vast amount of technical and industrial information on German war-time activities has accumulated as a result of the many investigations carried out. In this volume the results of these investigations are correlated and condensed, resulting in an exhaustive summary of the developments in the industry, surveyed from all angles. It is an Overall Report and it has been prepared in a very concise and useful form. The Report is divided into nine sections covering: Blast Furnace Plant and Practice; Steelworks Plant and Practice; Mechanical Treatment; Foundry Practice; Steels, Ferro-Alloys, Hard Metals; Heat Treatment; Cutting; Joining, Repairing, Fastening; Coatings (including Cladding and Bonding); Research and Testing.

Critical analysis and comparisons of pre-war and war-time practice are given, deviations from British and American practice, with their resulting advantages or disadvantages, are stressed; trends, induced by material shortages or by availability of new alternative materials or processes, are recorded; and the possibility of future application of war-time innovations is discussed. A section on research shows the close link between German investigators and the industries concerned and surveys the iron and steel research centres, reviewing their specialised work. An appendix to each section gives full reference to the original Reports surveyed and to other relevant reports and German documents. There is also a comprehensive index.

B.S.

THEORETICAL STRUCTURAL METALLURGY

By A. H. Cottrell. Published by Edward Arnold and Company, 41 & 43, Maddox Street, London, W.1. 256 pages, (price 21s. net.)

IT is pleasing to find that a metallurgist has at last written for students of metallurgy an account of the theoretical physics underlying so many of the problems of structural metallurgy and its application to such problems.

Dr. Cottrell has performed his task with commendable skill, particularly in his handling of the mathematics necessary for the understanding of the subject. This has been kept at a level which is within the capacity of most present-day metallurgy students although, in places, some who were trained in earlier decades may find it rather difficult to follow.

In the first six chapters Dr. Cottrell considers the structure of the atom and the nature of interatomic forces and develops his subject by describing the crystal structure and electron theory of metals. In the next five chapters the thermodynamic approach to phase changes in alloy systems is discussed while the last

three chapters deal with diffusion, the order-disorder change and phase precipitation by nucleation and growth.

While it is conceded that no other theoretical approach is satisfactory the reviewer finds the treatment of thermal equilibrium diagrams from the thermodynamical point of view rather illogical. So long as the form of the diagram is known a suitable system of free energy curves which "explain" the form of the diagram and the way equilibrium depends on temperature can be sketched. In the absence of a diagram, however, the construction of free energy curves is quite a different matter and it would therefore appear that to approach equilibrium diagrams from the point of view of free energy consideration, at the present time, is very largely begging the question. It cannot be assumed, however, that this state of affairs will exist indefinitely and discussion of the principles involved is both useful and desirable.

To those metallurgists who sometimes wake with a start, fearing redundancy, after dreaming of the young graduate of 1949 or '59 who; by the slick application of wave mechanics or statistical thermodynamics and no more apparatus than pencil and paper will proceed to solve all outstanding works problems, this book will come as a great relief for it demonstrates very clearly the tremendous advances that are necessary in theoretical metallurgy (or physics) before the properties and structure of an alloy or even a pure metal can be predicted with quantitative exactness. That this is so, is, of course, no reflection on Dr. Cottrell who has been careful to show the extent to which physical theories account for the experimental facts.

This book can be recommended confidently to all metallurgists, including those who are no longer considered students in the narrow sense, who wish to understand more fully the fundamentals of physical metallurgy; but as pointed out above, the reader must not be disappointed if the solutions of many problems are not found, for as Dr. Cottrell points out in his preface: "The science of metallurgy still faces many major problems, a fact which is both pleasing and provoking."

E. C. Ellwood.

NON-FERROUS CASTINGS

By R. F. Hudson, with Foreword by Mr. G. T. Hyslop, President of the Association of Brass and Bronze Founders, 282 pages and 62 illustrations and diagrams. Published by Messrs. Chapman & Hall, Ltd., Essex Street, London, W.C.2. Price 22s. net.

Although one standard British text-book on this subject already exists, the present book is welcome. It is to be regretted, however, that greater care was not taken in its preparation.

The author has obviously derived much benefit from his experience in the non-ferrous casting industry and both the student and the practical foundryman will find much to stimulate their interest. Criticism is confined in the main to the confused method of presentation of the first four chapters—Alloying Constituents and Fuels; Refractory Materials, including Moulding Sands; Core Sands; and Mould and Core Facings. The six pages on Alloying Constituents make good reading, but it is questionable whether the student or the foundryman will gain much of value from the few pages on Fuels. The main criticism, however, is with reference to the second chapter—Refractory Materials, including Moulding Sands (not the happiest of titles)—in which refractory materials *per se* occupy ten pages, moulding sands twenty-eight pages, and the remaining thirteen pages relate to Sand Testing, which, in a book of this kind surely deserves a section to itself, rather than be hidden away behind "Refractory Materials." Again, Core Sands, treated in sixteen pages, receives a chapter to itself. It is suggested, when the author is revising this excellent book, that he makes Fuels and Refractories his first chapter, with a certain amount of expansion of the fuel section; then chapters on Sand Testing; Moulding Sands; Core Sands; and Mould and Core Facings, concluding this earlier part of the book with a chapter on Alloy Constituents, expanded beyond the extent given in his present chapter. Such an arrangement would eliminate the impression of confusion which undoubtedly exists when reading these earlier chapters. At the same time, it must be emphasised that such comment does not apply to the subject matter and in no way to the later chapters. Indeed, many will be indebted to the author for an excellent chapter on that controversial subject, the Casting of Standard Test-Bars.

The author undoubtedly appreciates the true function of the technical man in the foundry and shows real enthusiasm for salvage and repair and also for examination of defects. This latter item is not left merely as a catalogue of faults, but is augmented with an analysis of causes and recommendations for curing the various sources of trouble. To this end, two excellent appendices have been included to supply typical examples of the defects in question. The general excellence of most of these photographs throws into relief the very poor quality of some of the earlier photomicrographs. Those of Figs. 2 and 3 suffer from (very) inferior preparation, faulty illumination and, in at least two instances, the surface of the specimen is not perpendicular to the illuminating beam. The later photomicrographs, included in the second appendix, show the author's technique for metallographic preparation to be of a high calibre, thus making inexcusable those inferior cases to which reference has been made. Again, magnification has been omitted from the earlier photomicrographs, so detracting further from their value. It is to be hoped that the author will rectify these faults when revising and so eliminate quite unnecessary faults from a very promising book.

K. G. Lewis.

POWDER METALLURGY IN GERMANY DURING THE PERIOD 1939-1945

This review of German powder metallurgy, published by His Majesty's Stationery Office, has been specially written by Mr. R. A. Hetzig for the British Intelligence Objectives Sub-Committee Group II at the Ministry of Supply.

Some interesting statements are made in this report about the ingenious way in which the Germans used this new technique. Particularly iron and steel showed some very interesting developments. Over 1,000,000,000 iron and sintered iron shell driving bands were produced in Germany. Powder aluminium and magnesium are reviewed and specific mention is made of high temperature application of sintered metals. A section is devoted to the review of nickel accumulator plates produced from carbonyl nickel or cupro-nickel powder.

The report contains 11 pages of references to German reports, published and unpublished, and special documents dealing with this subject. Price 6d. (post free 7d.).

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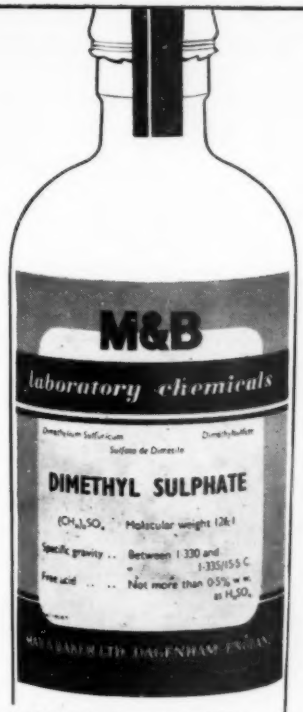

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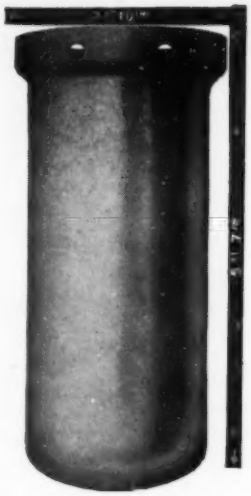

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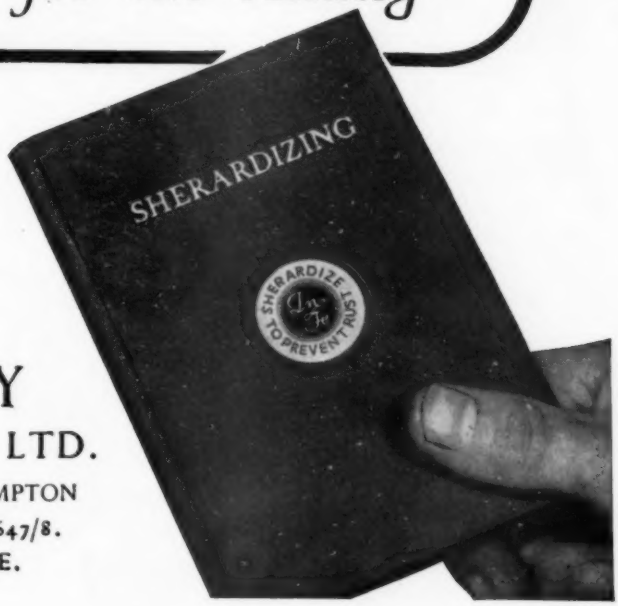

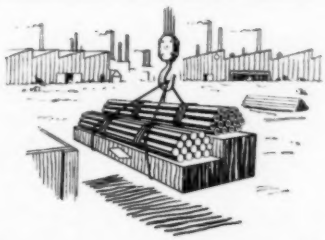

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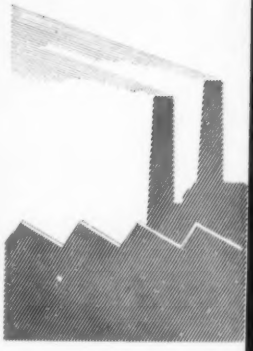

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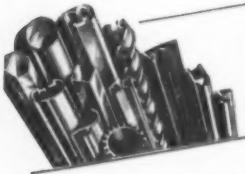

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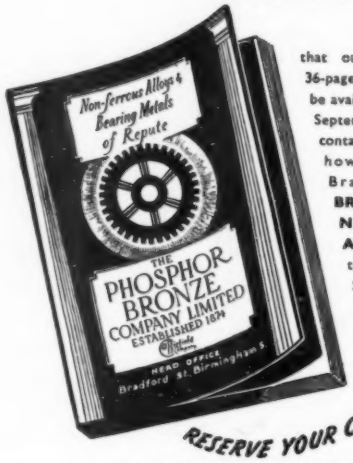
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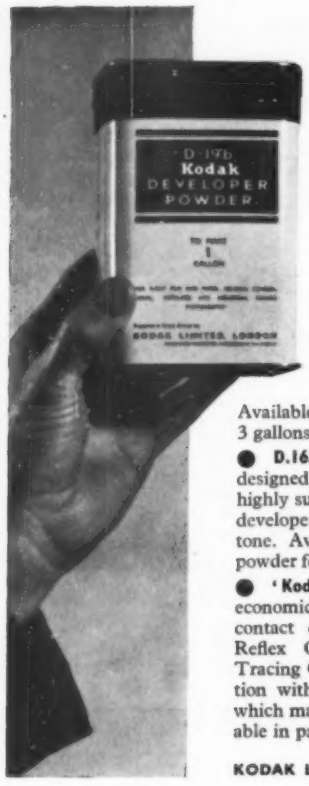

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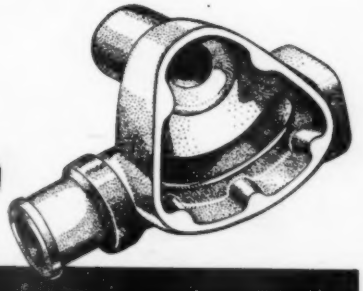

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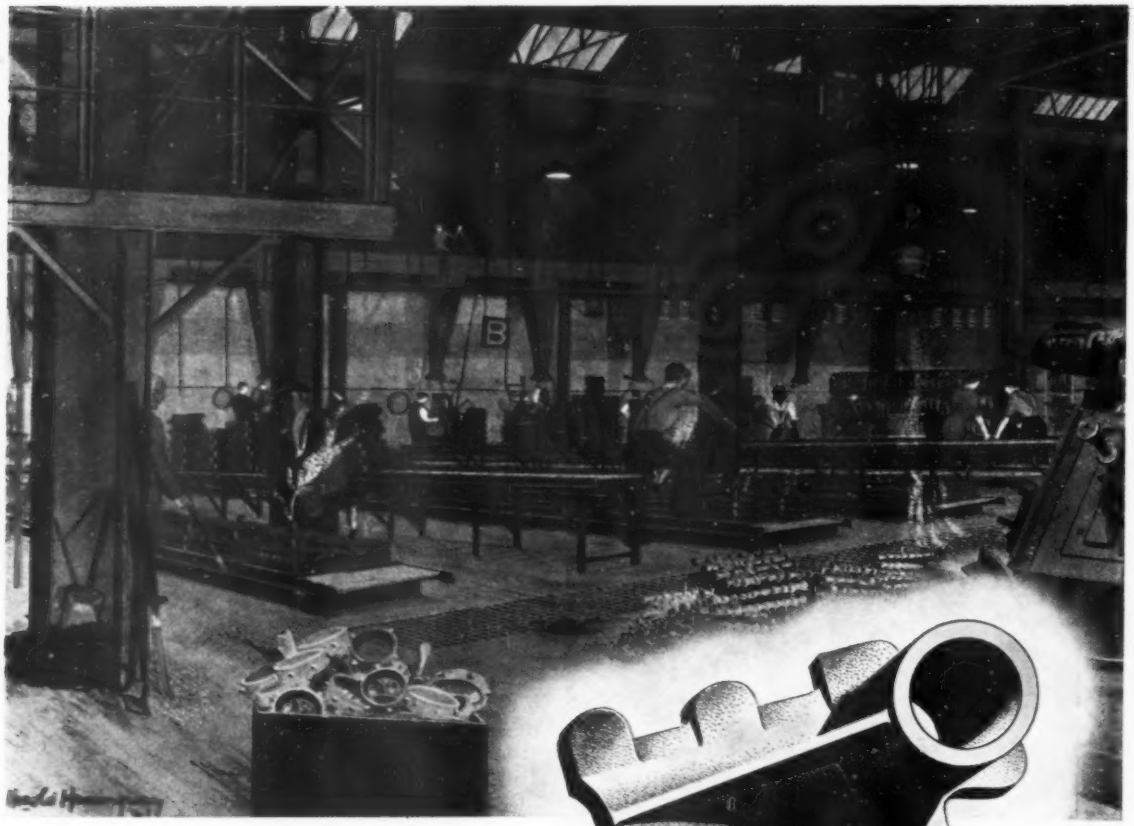

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